THAYER

Windmill Electric Plants

Electrical Engineering

E. E.

1909

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WINDMILL ELECTRIC PLANTS

BY

WILLIAM SUMNER THAYER

B. S. University of Illinois, 1905

THESIS

Submitted in Partial Fulfillment of the Requirements for the

Degree of

ELECTRICAL ENGINEER

IN

THE GRADUATE SCHOOL

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May 21, 1909.

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

WILLIAM SUMNER THAYER

ENTITLED WINDMILL ELECTRIC PLANTS

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF ELECTRICAL ENGINEER

E. Dwight H. Waldo.
In Charge of Major Work

Morgan Brooks
Head of Department

Recommendation concurred in:

L. P. Breckenridge.
F. D. Crawshaw

Committee
on
Final Examination

145017

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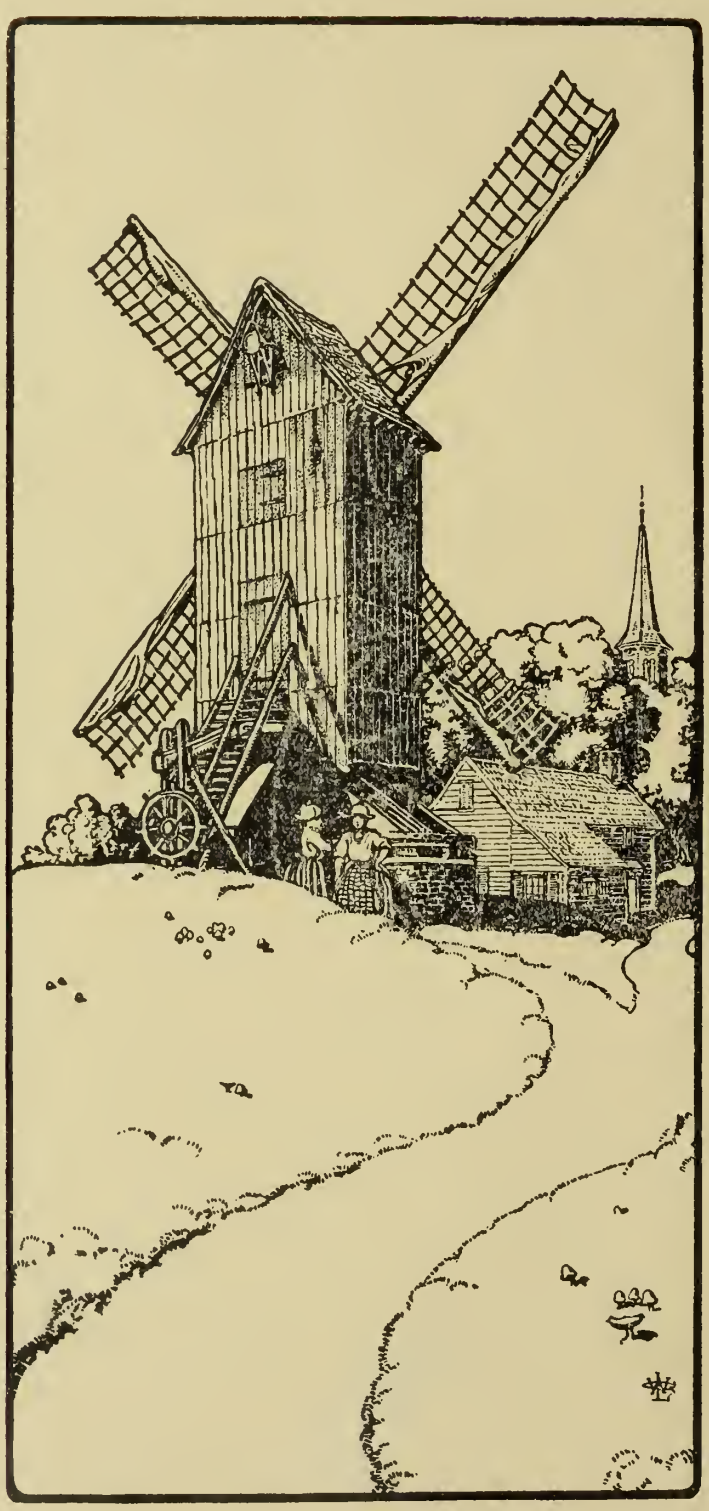

P R E F A C E

The purpose of this Thesis is to show what has been done along the line of Windmill Electric Plants, together with a somewhat theoretical discussion of the windmill itself. Improvements are suggested, and the calculation of a small plant using Tungsten lamps is given. The Thesis is divided into the following sections:

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I N T R O D U C T I O N

Owing to the recent development of the Tungsten incandescent lamp, which consumes 1 to 1 1/2 watts per candle-power and which has a positive temperature co-efficient, the windmill electric plant has very much greater possibilities to-day than when the carbon lamp was the only small electric light.

To obtain motive power at the least possible cost, is a question that so often arises that the windmill, the most economical of all prime movers, appears to deserve more attention than it receives. Wind, unlike water, is not limited to place or in quantity, but may be obtained almost everywhere, and is free to all. Furthermore, it entails no expense in itself. This cannot generally be said of water power, which usually involves the construction and maintenance of dams, conduits, to say nothing of the periodical cleaning, in some cases, of ponds.

The great drawback to wind power is, of course, its irregularity and uncertainty, and although a fall of water is subject at times to drought, flood, or frost, it will ever be superior to wind on this account, when it can be obtained. In the absence or insufficiency of a water-fall, it may, therefore, be profitable to employ a windmill, if the work to be done admits of suspension during a calm or consists of the storage of energy for future use.

The advent of suction gas plants and the adoption of crude oil have so cheapened power production by internal combustion engines that it is scarcely worth while to depend upon wind power for work of the first nature, except in those districts where fuel is difficult to obtain. Far wider possibilities exist, however, for an accumulated energy system, such as the raising of water to reservoirs for supply purposes, the generation and storage of electricity for lighting or power, and possibly, to a limited extent, the compression of air into storage tanks.

Wind is due to the movements of the atmosphere in recovering a state of equilibrium. The condition of unstable equilibrium is brought about by changes of temperature or humidity, which alter

the density of the air in different places. If one portion of the atmosphere becomes heavier than another, it will, in accordance with the law of gravity, rush into the lighter or less dense area, and so produce wind which will continue until equilibrium is restored. It follows, therefore, that, other things being equal, the denser the air, the greater its pressure, so that a cold winter wind will possess more power than a warm summer one, assuming the velocity and other conditions to be the same in both cases. For a like reason, winds at a high altitude are not so effective as those of the same velocity at sea level.

Owing, presumably, to the friction of the earth's surface, the velocity of the wind increases with the height above ground level; it has been computed by Mr. Thomas Stevenson that if the velocity at a height of 50 feet is 1.0, it will, at 25 feet, be nearly 0.9, but at 100 feet it will amount to 1.2. These results indicate the advantage to be derived from mounting windmills on high towers.

The most important consideration with regard to the wind in the present connection is its average velocity and duration. As these conditions are necessarily governed by the situation, it is possible only to generalize. In Great Britain and in the United States the average rate throughout the year, at inland stations, may be taken as about 7 1/2 miles an hour; but in some exposed situations, in the neighborhood of the sea, it amounts to as much as 16 miles an hour. A speed of 10 miles an hour is generally attained during one-half to three-quarters of the year, according to locality, and a 16-mile wind may be expected, under favorable conditions, for about one-third of the year. Unfortunatly, the windy periods do not occur at regular intervals, and calms of several days must be provi-

ded for.

Since the pressure of the wind varies as the square of the velocity, and since the power is the product of both velocity and pressure, then the power varies as the cube of the wind velocity. Theorectically, the power of a windmill follows the same law; practically, however, it is modified by two factors.

With light breezes the power absorbed in overcoming the friction of the mill will bear such a large proportion to the kinetic energy of the wind that the actual power available for doing work will be very small; hence, at the lower end of the scale the working capacity will increase very rapidly with every increment of wind speed.

On the other hand, with high wind velocities the speed of the windmill cannot be permitted to increase in the same ratio, so that a large proportion of the wind force must be run to waste. From these considerations it will be apparent that to obtain the greatest effect from the wind's varying impulse, the work to be done by the mill should augment with an increase of speed in the same proportion as the wind pressure varies with the velocity.

When circumstances permit, the raising of water by centrifugal pumps would fulfill these conditions, as the discharge of a pump of this type increases with the square of the velocity. Dynamos for charging accumulators, so constructed as to generate a constant voltage under wide speed fluctuation, afford another example. In milling or similar work, where an attendant is present, the load can, to a great extent, be adjusted to the strength of the wind prevailing; if this is less than 10 miles an hour, it is generally regarded as of little use, but if over 20, sail has usually to be short-

ened or other regulation made to prevent any further increase in rotative speed.

The case is somewhat different with pumping mills of the annular disc type. It appears that a well constructed windmill will just commence to run with a breeze of 3 to 4 miles an hour. With a 5-mile wind, it will pump an appreciable quantity of water, but a 10 mile windwill, in some cases, multiply this amount by ten.

The water raised with a wind velocity of 15 to 16 miles is generally a ten-mile wind; up to 20 miles there is a very slight increase, and beyond this the quantity is usually constant owing to the action of the governor..

The windmills in present use may be broadly divided into two classes; viz., the old fashioned type with four, five or six "sweeps", and the modern annular disc wind wheel. Horizontal mills have been built, and, curiously enough, this design has attracted the greatest attention on the part of the inventors, but their performance is so indifferent that it is not proposed to devote space here to them.

The driving mechanism of the older class of mill is of two kinds,- the sweeps, Fig. 7, consist either of wooden frames covered with canvas, or the sail surface, Fig. 8, is composed of a number of shutters capable of turning upon axes, so as to oppose more or less area to the wind. The sail sweep, notwithstanding its disadvantages, is still in extensive use; all that can be said of it is that it is light and cheap, and gives a rather more powerful drive than a shuttered sweep of the same size. Its drawbacks are that it is not self-regulating, and the surface exposed can be only approximately adjusted to the load, or the wind, by stopping the mill and making the alteration

by hand. This is a difficult and dangerous operation in squally weather. Attempts have been made to remove this objection, but, so far as can be ascertained, none of the remedies have stood the test of time.

It would be out of place to enter upon a detailed description of the shuttered sweep, but it is pertinent to say that there are two systems under which regulation is effected. In one plan the shutters in each sweep can open or close independently of those in the others, by being connected, through bell cranks and rods, to a radial arm. In the other, the shutters in all the sweeps act simultaneously, the pressure being applied by a weight acting upon a rod which passes axially through the main shaft.

The first method has the advantage of equalizing the load on each sweep, whereas the second enables adjustments to be made while the mill is running. A combination of both systems would probably produce the best results, and there appears to be no reason why the resistance of the weight should not be controlled by a centrifugal governor in the event of a very steady drive being required.

The most suitable angles for the "weather" or twist of the sails at different parts of their radii have often formed the subject of mathematical investigation. It is, however, beset with difficulties, as other factors, such as the width and number of vanes, enter into the question, and the writer ventures the opinion that a series of experiments with an artificial wind is the only means of providing reliable data.

Smeaton's famous trials with models on a whirling table were of this nature, and appear to be the only records in the English language that have been made public: but they were made a century

and a half ago, and obviously stand in need of revision. A few years back, however, the Danish Government caused a set of experiments to be conducted, the object of which was to determine the form of a windmill to give the greatest mechanical effect within a given diameter.

These experiments, which were made with a large number of models and a wind produced by an electric fan, were confined by observation on large mills, and go to prove that the form of the sails should be as follows:

The mill, Fig. 7, should have four arms, the sail surface being approximately rectangular, with a width of one-fourth to one-fifth of the radius and a length of about three-quarters of the radius.

The cross-section of the vane, at the tip, should not be a straight line: the leading edge should be bent or curved to an obtuse angle with the rest of the sail. The breadth of the leading or bent portion should be one-fourth to one-sixth of the total breadth of the sail. The bevel of the chord or of the straight line subtending the angle of the bend should be 10 degrees at the axis if the sail were continued through the whole length of the radius.

When the mill has a substantial body, the extremities of the sails, if they are of canvas and weathered, as above indicated, will flap when passing it, owing to the compression of air between them and the body. To avoid this the tips of such sails should be set square, so as to coincide with the plane of motion, and the versed-sine of the arc should be increased to from 4 to 6 per cent.; but at a distance inwards equal to the width of the sail, the weather angle should be the same as at the extremities of the former type.

The speed of the tips should be 2.4 times that of the wind,

except when they are square, in which case the speed should be increased to 2.8.

The work yielded by a mill constructed under the foregoing conditions should be 0.04 foot pounds per square foot of sail surface, with a wind velocity of 3.28 feet per second, and will increase with the cube of the speed of the wind subject, of course, to the limitations previously pointed out.

The conclusions cited agree, in the main,with existing practice, and confirm Smeaton's contentions that increasing the area of the sails relative to that of the circle swept by them, beyond a certain point does not augment their power in the same proportion; in fact, if pushed too far the effect will be diminished, owing to want of space between them for the air to escape.

According to the Danish experiments, a four-armed windmill gives greater power than a disc sail wheel of the same diameter when the speed of the former does not fall below a certain ratio to that of the wind; if this happens, its power rapidly falls off. This is explained by the fact that the weather angle for any part of the radius is most effective for a definite velocity ratio of that part to the wind, but is so only when this is maintained. As a consequence, a windmill of this type will not work in very light winds unless the load is very much reduced: for the same reason a considerable breeze is required to start it. Increased sail area, either by widening the sails or adding to their number, coupled with steeper weather angles, would not doubt lessen this defect, and would probably give a more steady turning movement at some sacrifice of speed and power.

The disc mill having a relatively greater sail area with its vanes at more advantageous angles possesses a high starting

torque and capacity for work in very high winds. These features have enabled it to supersede the old fashioned mill for operations that have to be carried on as frequently as possible. A much slower speed in small sizes is advantageous rather than otherwise, especially when they are coupled to pumps.

Unfortunately, no data of the nature referred to in connection with the old form of windmill seems to exist for this type, but in 1903 some very important trials were carried out by the Royal Agricultural Society of England, from which some useful conclusions may be drawn. These trials were of a competitive nature, and were instituted to provide trustworthy data for the guidance of intending users of windmills for pumping.

In judging the performance, the working of the windmills and pumps as combined machines was considered, and, besides pumping efficiency, other points, such as the design and stability of the tower, cost, attention required, maintenance, etc., were taken into account. It does not necessarily follow that each windmill was provided with a pump of the most suitable proportions, and this circumstance would, of course, effect the question of power efficiency. The same remark applies to governing; to enable an exact comparison to be made, the systems employed in the several cases should be identical.

The windmill, Fig. 9, that was awarded the first prize was, however, so far in advance of its competitors in respect to the amount of water raised in a given time that the following leading particulars may be useful:

The diameter of the wheel was 16 feet. It had eighteen blades, with a sail area of 131.32 square feet; the available clear-

ance area between the blades was 67.93 square feet, and that of the centre of the wheel 30.88 square feet. The blades, Fig. 10, were 1 foot, 11 1/4 inches wide at the outer end, 11 1/4 inches wide at the inner end, and 4 feet, 10 5/8 inches long. The vanes were curved hollow to the wind, to radii of 2 feet, 3 1/2 inches, and 1 foot, 6 inches at the outer and inner ends, respectively. The versed sine of the arc at the outer end was 2 1/2 inches and that at the inner 1 inch; the chords of these arcs were weathered to the plane of motion at an angle of 35 degrees at the tip and 40 degrees at the inner end.

This mill was fitted with a double-acting pump capable of raising two gallons per (double) stroke; the wheel made five revolutions to one stroke of the pump. With a 12-mile wind the horse-power of the water lifted amounted to 0.573, the efficiency of the pump being 97.61 per cent. The work accomplished was, therefore, 2.39 foot pounds per second per square foot of sail surface, representing a utilization of about 16 per cent. of the total horse-power contained in the cylinder of wind intercepted by the mill. The ratio of the peripheral velocity of the wheel to the speed of the wind works out 1.05 to 1. It will be interesting to compare the results given by this mill with what should be obtained for the four-armed type.

According to the formula previously quoted, the power developed with a 12-mile wind would be 6.16 foot pounds per square foot per second; but as the sail surface in this case would amount to only about 36 per cent. of that of the disc mill, the final result, diameter for diameter, is slightly in favor of the latter

It would occupy too much space to give the particulars of the other mills entered for trials. A careful analysis of their

performance has, however, been made which warrants the opinion that, as far as present knowledge goes, bothing is gained by providing sail area for more than about 66 per cent. of the total surface of the wheel.

The most suitable angle of weather for the tips of the vanes, owing to some of the wind being deflected, appears to be about 35 degrees for practical purposes, when their velocity is the same as that of the wind, which seems to be about the best ratio.

As to the number of vanes, this is a mooted point. It is held by some that the bulk of the work is done at the front edge, and that in consequence the greater the number, the higher the efficiency. As a matter of fact, the wheel described possessed the fewest; of the remaining five of those selected for the final trials, one had 42, another 32, and the remainder 24 vanes.

The amount of water raised by these five was much the same in each case and averaged about one-half that pumped by the wheel with eighteen blades. Results so comflicting preclude making any definite conclusion

One of the principal German builders has been developing the "Soerensen" system. Apparently the theory that has been proceeded on ever since windmills have been in use is - "the larger the surface the greater the power. The "Ventrokat" and "Windrose" types of German wheels of the highest efficiency were tested with a Soerensen wheel, all being of the same diameter, and the results were as follows:

	Ventrokat	Windrose	Soerenson
SURFACE IN CENTIMETERS	7440	2976	1188
POWER IN KILOGRAM SECONDS	1.59	1.77	2.34

The extreme superiority of the Soerensen motor over other existing types is due to a large extent to the form of its vanes, particularly at their ends, where the greatest wind pressure is exerted; but the unusual distance between the vanes adds an element of power, the importance of which has hitherto been completely overlooked. This space not only permits the passage of wind between the vanes so that the latter meet with greatly decreased resistance, but a vacuum is seemingly created, and this, with the absence of back pressure, accelerates the motion of the wheel. They are also said to be safe during severe storms.

A special speed regulating device is provided with the Soerensen motor for driving the electrical generators at a constant speed, a slight variation of speed being noted regardless of the wind velocity.

Many systems of governing have been devised, but those in general use may be classified as follows: The hinged vane and the canting wheel. In the former type the vanes of the wheel are hinged in such a manner that they can give to the wind pressure when it exceeds a certain amount, and more or less present their edges to it and thus allow a greater proportion of wind to pass through the wheel without doing work. The resistance to opening is controlled by a weight or springs, or occasionally by a centrifugal governor.

The canting wheel method of governing is usually carried out in the following manner:- Normally the wheel is kept facing the wind by the action of a tail vane, but the axis of the wheel, instead of being placed on the centre line of the turntable or head, is fixed a little to one side so that there is always a tendency for the wheel to throw out of the wind. The leverage of the tail vane is,

however, made sufficient to overcome this, but instead of being rigidly fixed, it is hinged to the head, and its right angle position relative to the wheel, is maintained by the action of a weight or spring. If the wind exceeds a certain pressure, the weight or spring yields to it and the right angle position is no longer preserved, with the result that the wheel turns more or less obliquely to the wind and receives its force with diminished effect.

This form of governor, although it may appear crude at first sight, gives surprisingly good results, and made a better showing during the trials than the more complicated hinged vane type. For mills of over 20 feet diameter the latter is, probably, more suitable; in fact, the former could not be applied to very large wheels, as their steerage is accomplished by a revolving fantail, similar to that employed in the old style tower mill.

The hinged vane governor has the advantage that the weather angle of the blades can be altered while the mill is running, and the speed of the machinery adjusted to meet requirements.

On account of the far higher efficiency of the four-armed mill, per unit of surface, constructional considerations will, no doubt, enable it to compete with the disc type when a motor of large size is required.

The electrical utilization of wind power has obtained considerable popularity in Europe. For several years past the Danish Government has been conducting a series of experiments with windmills to ascertain the relative amount of electrical power that can be generated. In this country similar experimental tests have been made and, although the instances are not numerous, they are somewhat isolated. The data furnished indicate a useful future for this form

of prime mover. This is particularly true of the agricultural region of the west, where innumerable windmills have been constructed in the past ten years for irrigation purposes. The question of harnessing the windmills to dynamos for the generation of electric light and other electric power is likely to receive the attention of the farmers within the next few years.

Probably one of the first experimental efforts made to utilize wind power for generating electricity was that of Dr. Charles F. Brush, the inventor and pioneer in electric experiments who installed a windmill plant at his home in Cleveland, in 1889, to light his house and laboratory. This windmill generating station is in use today, and during its 20 years of operation has furnished an excellent example of what may be expected of windmill electric plants in that section of the country. The fact that the wind velocity varies considerable in different states should be taken into consideration, and the value of this form of prime mover may prove more profitable in one section than in another. The average wind velocity for the year must be considered, rather than for a month or season. The simplicity of the windmill generating plant is one of the chief features. In Dr. Brush's plant the dynamo is connected by pulleys, so that 50 revolutions are made to every one of the windmill. The normal speed of the dynamo is 500 revolutions a minute. In an ordinary wind with a velocity of 8 miles per hour this windmill drives the dynamo at its normal speed, developing 12 K.W. Unfortunately, however, a wind velocity of 8 miles per hour cannot be depended upon steadily in the vicinity of Cleveland, and a storage battery is necessary for satisfactory operation. The average wind velocity for the United States is given as 8 miles per hour, but in many parts of the country a ve-

locity of 4 or 5 miles is maintained throughout the summer. The dynamo of this plant is arranged to be put into operation automatically at 330 revolutions per minute. The working circuit opens automatically at 70 volts, and closes at 75 volts. In the basement of the house are installed 12 batteries of 34 cells each, and these are charged and discharged in parallel. With each cell having a capacity of 100 ampere hours, it is possible to light 100 - 16 candle-power incandescent lamps for an hour. The successful working of this plant for lighting the house and laboratory has demonstrated the value of the windmill generating plant for light loads.

The windmill electric plant at Wittkeil in Schleswig has a wheel whose diameter is about 40 feet, and an effective wing space of nearly 1000 square feet presented to the wind. The windmill develops 30 horse-power with a normal speed of 11 revolutions per minute. It operates a shunt generator that makes 700 revolutions per minute, and develops 160 volts and 120 amperes. This full load is developed when the wind is blowing at 8 miles per hour. The windmill furnishes power to light the town of Wittkeil. The lamps and also small motors are connected to the battery, which maintains a voltage of 110 volts. The battery has a capacity of 66 Kilowatt hours. This plant has proved so satisfactory that it is being enlarged, and as a permanent lighting station it is likely to prove of unusual importance in the development of generation of electric power by windmills.

The windmill electric lighting plant at Marble Head Neck, Mass., consists of a 20 foot Eclipse windmill mounted on a hard pine tower 75 feet from the ground. Power is transmitted by bevel gears and shafting to the house at the base of the tower. The generator

is a 2 K.W. Lewis machine, but should have been 3 K.W. because of the mill capacity. 90 volt lamps are used. The battery consists of 46 Bradbury-Stone cells of 200 ampere hour capacity. An automatic switch closes the circuit between the generator and the battery when the voltage rises to 100 volts, and opens it when the current ceases to flow into the cells. The mill furnished 130 lamps from May 1st. to Nov. 5th. A 10-mile breeze gave 3 to 5 amperes at 110 volts, while a 20-mile wind gave 18-25 amperes at 110 volts. The generator was too small to take more load at higher velocities of wind. It will be remembered that the Lewis windmill charging generator has a series coil on the field wound differentially to the shunt field, so that the machine delivers current at constant potential at variable speeds. The experiment of cutting out the differential winding and running the dynamo as a simple shunt wound machine was tried. It worked beautifully in light winds, for as the machine speeded up the load would come on the generator and prevent the mill from turning any faster. As long as the power of the windmill was limited this worked very well, but when a strong wind came there was so much power in the wheel that the generator could not take care of all the power, and so would have been injured if left running. The advantage of the differential winding is that it allows the dynamo to speed up without overloading it. The cost of a plant similar to that just described was estimated to be about $1500, but as stated above, its capacity is greater than that actually installed owing to the low capacity of the generator. It is worthy of note that not once during the entire summer was the power interrupted owing to a lack of wind.

Among the notable installations of this kind is one at Askov, Denmark. This town is supplied with light from an electrical generator operated by a windmill. The installation is said to have given excellent satisfaction for a number of years. There are two windmills, the older one has wings about 40 feet in diameter, the other has wings about 75 feet in diameter. The wings of these windmills were so arranged as to be placed automatically against the wind, the screen flaps of the wings closing or opening automatically with the velocity of the wind to supply the necessary regulations. Figs. 1 and 2 show the details of construction and arrangement of the apparatus as well as the electrical connectionsof the storage battery, dynamo and regulating devices designed, in order that the dynamo might yield practically a constant current regardless of the strength of the wind in charging the storage battery.

Professor La Cour designed two automatic devices for transforming the wind power to electric energy and storing it automatically without continued supervision. The storage battery acts as a regulator, being charged and discharged simultaneously if desired, the current being utilized for lighting or power purposes. The wind-driven electric generator automatically supplies current to the accumulators when operating at the proper speed. As soon as the voltage of the generator driven by the windmill exceeds the voltage of the storage battery, the connection is automatically made and the current charges the storage cells. In case the speed of the dynamo is too low to supply the necessary voltage the circuit from the dynamo to the storage battery is automatically broken.

The automatic switch utilized for this purpose is shown in Fig. 1, its connections being shown in Fig. 2. It consists of two mer-

cury cups, Fig. 1 (K-1 and K-2), together with the horseshoe magnet (M) arranged to rotate about (O), with its poles approaching those of two electro-magnets, which are wound with a heavy wire (SS), and fine wire (ss), the latter being connected at each end to the terminals (A) and (B). The current is conducted from (A) to (B),continually, through the fine wire (ss), the connection through the heavy wire (SS) being made only when the right-hand end of the copper rod dips in the mercury cup (K-2).. While the voltage of the dynamo is lower than the voltage of the storage battery, a current passes through the fine wire (ss) magnetizing (P) sufficiently to draw the magnetic poles to the right so that the mercury contact is broken at (K-2). If the dynamo attains the necessary speed so that its voltage is higher than that of the accumulator cells the mercury contact is closed at (K-2), as the magnetic poles will be drawn to the left, and the current will then be charging the storage battery through the heavy winding of the electromagnet. In case the wind dies down to such a point that the dynamo is not supplying a sufficient voltage the mercury contact is again broken at (K-2) and remains broken until there is sufficient pressure at the dynamo terminals to again charge the storage battery.

In order to maintain the current constant regardless of the strength of the wind another device is provided, as indicated in Fig. 2. The dynamo (M) is driven by the belt (rr), the pulley (C) of the intermediate shaft being mounted on a movable arm having a counterweight (L) hinged at (D). This pulley is driven by a vertical belt (R-1,R-2), driven from pulley (A), which is operated by the windmill. The belt tension controls the maximum pull, which can be transmitted by the belt. As soon as the resistance has

reached the value of the driving force the belt will begin slipping and the driving force will remain practically constant. This arrangement is utilized not only with windmill electric plants, but also for dynamos driven from car axles, the belt slipping as soon as the speed of the train exceeds a given amount.

In a test by Professor La Cour to ascertain the efficiency of this device, it was found that as the speed increased from 837 revolutions the current in amperes remained practically constant at from 40 to 41 amperes. It is claimed that this double regulation allows electricity to be generated and stored automatically, utilizing the wind as a source of power with reliability, as shown by the last two year's operation at the experimental plant at Askov.

An arrangement has also been designed so that these wind motors are operated successfully in connection with steam engines, resulting in a great saving of fuel when there is sufficient wind. The steam engine supplies the necessary additional power during a light wind and acts as a regulator as to speed, while it never has to turn the windmill when the latter is not operated by a sufficient wind.

It is held that the automatic regulation of the conical wind motor is of great value, this regulating being provided for by swiveling boards on the wings opened automatically by their centrifugal force as the speed of the rotation reaches a certain maximum desired.

The opening of these flaps allow the surplus wind to pass through the higher speed, the boards closing as the motor rotates at a slower speed when the wind decreases in velocity. A windmill of 15 H.P. capacity, designed on these lines, is capable of supplying

the necessary power for a dynamo for 150 incandescent lamps continuously, or a larger number in case the storage battery is installed with a capacity sufficiently large for storing the entire output of the mill and generator for several hours during the day time.

At Askov the electric plant run by the windmill supplies the residences of the town with electric current, the constant normal current being 60 amperes at a pressure of 220 volts. A petroleum engine has been installed for use as a reserve in case of several days calm weather. This is found to be much cheaper than a storage battery. The engine thus runs the dynamo during a calm. The engine is best mounted along with the dynamo so that it can be thrown on to the latter with a clutch, while the shaft of the windmill is thrown off in like manner. The plant has given excellent satisfaction, requiring little care or attention. It is stated that the man in charge has been away from the plant for two days at a time when the petroleum engine was not required.

The storage battery has a sufficient capacity for supplying the maximum amount of energy required during 48 hours, or 500 incandescent lamps as well as some arc lights and a few motors. The capital cost of such a plant is given as follows:

Windmills	$ 825.00
Oil Engine	825.00
Battery	1,375.00
Dynamos	250.00
Automatic Disconnecting Gear	95.00
Switchboard, etc.,	95.00
Land	725.00
Mains	350.00
Total --	$ 4,540.00

The annual cost of supervision, lubrication and running expenses of windmill amounts to $55; running of oil engine (30 days out

of the year) $32.50. The receipts amounted to about $700 per annum, giving a profit of nearly 12 per cent. of the capital cost. The current is supplied from this windmill plant at 4 cents per Kw. Hr. for motors, and 13.5 cents per Kw.Hr. for lighting purposes; the same rate as is paid by the consumers in Copenhagen.

For ordinary farm use Prof. La Cour estimates that a small windmill plant with dynamo and petrol motor will cost about $960 to erect. He also asserts that during periods of calm, horses might be used as the prime mover, thus eliminating the cost of the petrol motor.

The british steamer "Discovery", which recently went to the South Polar regions, has some special lighting features. On the upper deck is a large windmill which drives an electric generator for charging storage batteries. Oil in sufficient quantities would take up more room than could be spared after the storage of food and scientific instruments had been provided for. The ship is, therefore, lighted throughout by electricity. The windmill and generator are both portable, so that they can be set upon the ice and connected to the battery by a flexible cable. The difficulty of the variations of wind velocity has been overcome by Mr. Bergtbeil, who designed the entire plant. The mill drives two generators, to one of which is fitted a device which equalizes the current, offering greater resistance when the wind is high,and less when it falls. Thus, the number of revolutions of the generator can vary from 500 to 2000 without causing any appreciable difference in the charging current. When the mill stops the current is automatically opened, and when it starts the current to the battery is automatically closed. This plant supplies over fifty lamps in the ship. To prevent the batteries

from freezing they are placed next to the engine room.

A patent was recently issued which relates to a variable speed generator intended particularly for use with a storage battery in connection with the lighting of a train. The main generator is provided with two field coils, one of the coils being supplied with a constant current from the storage battery; the other coil is supplied with an opposing current whose strength varies directly as the speed of the train. The source of this latter field current is a separately excited generator which is connected to the main generator. Its field is excited from the battery as the main generator is. As showingthe regulation obtained by this system it is stated that a certain equipment for railway train lighting supplied 5 kilowatts. 33 volts at a speed of 50 miles per hour, and furnished 800 watts at 31 volts with the speed decreased to 22.5 miles per hour,without necessitating any change or adjustment of the brushes or the rheostats in the field circuits. See fig. 3.

In adapting the windmill generating plant to commercial purposes in this country, experiments have taken some peculiar form. In order to eliminate the storage battery the mill must be able to store up energy in some other way. A number of methods to do this have been suggested. At present the extra cost of constructing the storage battery makes the initial cost of the plant more expensive than the first cost of an oil or steam driven plant. After the first installation the cost of the operation is very little, and if it were not for the constant oversight of the storage battery the plant would work entirely without any watchman. The storage bettery requires the attention more or less of an electrical expert, and the labor question enters into the problem of operation. By eliminating

the storage battery the cost of installation, the repair items, renewals, and the labor items would all be reduced.

One patent tested in this Country was to utilize a compressed air plant in connection with the windmill. The mill is direct connected to the air compressor. The power thus stored up can be utilized as needed, but in this case the extreme amount of mechanism increases the cost of installation even more than the storage battery. The compressor, moreover, requires pretty constant watching,and the windmill generating plant approaches no nearer the self regulating and operating machine than before.

Another method has been employed which appears to contain some possibility for the Western farmers, where windmills are already in use for pumping water for irrigation purposes by means of storage tanks. The windmill pumps the water to a great height and then the pressure developed by the falling water is used for driving a water turbine. In this case the dynamo is driven very much like any hydraulic generating plant; any ordinary water motor and generator could be adapted to the work. The turbo-generating method of utilizing the windmill for electrical development would require nearly as much expense for initial installation as any of the other methods, but once in working order it would prove purely automatic and self-regulating. The great size of the tank required to develop sufficient horse-power to operate the generator is one of the draw backs to this system. The loss of efficiency would be considerable and the ordinary windmill now in use for electrical generation would have to be increased in size and supplemented by several others. The storage tank would have to be large enough to hold sufficient wwater to run the turbo-generator for at least 8 to 10 hours consecutively.

Even then the plant might be out of operation for 10 hours or more through the failure of the wind. All would depend upon the average velocity of the wind in the regions where the plant was installed.

The storage of water by means of windmills in reservoirs on the hill sides has been suggested, thus furnishing an artificial supply of water for hydraulic purposes. In this case a sufficient number of windmills might be installed to pump into a large reservoir that would never be exhausted. The result of such an experiment would certainly prove of interest to engineers; but it is somewhat doubtful if the returns would pay for the heavy outlay for the windmills and reservoir.

Let us work out a specific case where water is raised a certain height and stored in tanks prepared for the purpose, and see if it is a practical means for storage of power. On the basis that one horse-power would require the lifting of 33000 lbs. one foot in one minute, it is evident that it would require large storage tanks and much time to lifting up water to provide a supply of any practical value. To this must be added the cost and care of the water motor to utilize this stored up energy. A simple calculation shows that to furnish a constant supply of one horse-power for a day of ten hours would require the daily storage of 47000 gallons of water at a height of 50 ft. To accommodate this would require a tank 20 feet square, and 16 feet deep. To the expense of such a tank must be added the cost of the strong tower which would have to be built to carry it at such a height this load of nearly 200 tons.

The cost of receivers and motors for the utilization and storage of compressed air would in like manner largely neutralize any apparent utility of such a device.

To store up sufficient energy to run a one horse power motor for a day of 10 hours would require a set of cells whose weight would be from 1600 to 1700 lbs. They would occupy some 20 cubit feet of space, and with the windmill generator and general fittings would cost $600. or $700. There would be a certain amount of drawback to the use of this system in the fact that the handling of the battery necessitates some technical knowledge that must necessarily limit the range of its application.

Of the three systems, the last mentioned would seem to be the best, and with further improvements in the way of automatic devices for charging and discharging of the batteries, and in the use of tungsten lamps, we may look for a more extended use of this system.

The ideal windmill electric plant must be simple, automatic, reliable, efficient and cheap. It should be so simple in its construction and operation that a progressive farmer would have little trouble in taking care of it except, perhaps, in caring for the batteries. The generator must deliver power to the battery when there is a breeze stirring. The plant must be so designed as to get the maximum amount of power out of the windmill for every wind velocity. The power should be automatically cut off when the battery is fully charged. It must also be so designed that when the wind velocity gets so low that the generator voltage is lower than the battery voltage the circuit between then generator and battery will be opened, thus preventing the battery running the generator as a motor. The plant must be efficient, not only at the generating and storage end, but also at the consuming end.

The method of connecting the generator to the wheel of the windmill is worthy of attention. In all of the cases cited above the generator was connected to the wheel by shafting , belts, gears

and pulleys. They are all inefficient especially the gears. The modern method in engineering is the direct connection of prime mover and generator. Direct connecting the windmill and the generator would be efficient, but owing to the slow speed of the mill wheel, the generator would be very bulky for its capacity. The speed might be raised by one pair of gears to bring the generator speed about normal at the maximum operating speed of the mill. The disadvantage of either of these two methods is having the generator far from the ground. It would make inspection of the generator difficult especially in cold weather. It would also necessitate, probably, better foundation for the mill tower. The best way would be to have a vertical generator mounted on the ground directly under the windmill, and direct connected to the vertical shaft. The proper speed would be secured by one pair of bevel gears at the top of the shaft. There should be a clutch to disconnect the generator from the mill shafting when necessary.

The best kind of a generator would be a differential compound generator. This generator should be large enough to take care of all of the power which the mill could develop at its highest operating speed. The generator should have such a capacity that when running as a shunt generator it would keep the speed of the mill below its most efficient speed for that wind velocity. The differential series field could then be inserted and the series field shunt adjusted so as to make the windmill operate at its most efficient speed for all wind velocities. If it were impossible to have the mill run efficiently at all speeds, the shunt should be adjusted for maximum efficiency at the average wind velocity of that vicinity. Of course the shunt field rheostat could be used at high wind velocity

to secure maximum efficiency.

The shunt field should be connected directly across the battery. On calm days this circuit should be open. This might be done automatically by having a centrifugal device which would fly out at a little above speed for normal no-load voltage. This device would close the field circuit and keep it closed as long as there was wind enough to charge the battery. If the mill stopped the field circuit would be open automatically. This device would save some power which, on calm days,would be valuable. Having the field connected direct by across the battery would aid in the automatic charging of the cells. As the battery voltage rose due to the charge, the generator voltage would also rise proportionately for the same generator speed, thus keeping the charging current about the same. The knee of the saturation curve of the generator field should be at the same voltage as the battery is when each cell is about 2.05 volts so that as the voltage of the battery rises rapidly at the end of the charge the flux of the field will increase much slower. The finish of the charge should be at a lower rate than normal.

The tungsten lamp which consumes only about one-third of the power of the carbon lamp for the same candle power is a great advantage in a windmill electric plant. The tungsten lamp also has a much greater brilliancy and superior quality of light to the carbon lamp. On account of the positive temperature coefficient of the filament it is not as seriously affected by voltage variations as is the carbon lamp and any deviation from a constant voltage produces much less change in the candle power and the life. The tungsten lamp has a life of about 1200 hours and the candle power remains constant throughout its life as far as the eye can

detect. The tungsten lamp also has the advantage of being as efficient at low voltages as at high voltage, while a low voltage carbon lamp is inefficient. They are made commercially from a volt up.

Probably the best voltages for a windmill electric plant would be 100-125 volts; the standard voltages of lamps, heating apparatus, and small motors. Although, if a plant was to be used for nothing but lighting purposes, a lower voltage could be used efficiently.

The standard method of obtaining constant voltage on the lamps when storage batteries are used is the end cell switch. A cheaper and not much less efficient method would be to have in series with the battery a variable resistance large enough to make the maximum drop of from 2.5 volts to 1.8 volts per cell for one lamp, and enough current capacity to carry the current for all of the lamps. The current for power purposes, such as heating and motors, could be taken directly off the battery without the use of resistance for constant voltage. A water rheostat, which is very cheap, might be used for this purpose. The use of resistance seems a wasteful method of obtaining constant voltage, but it should be taken into consideration that the voltage on discharge falls off very rapidly the first few minutes in a 7-hour rate of discharge, then the voltage falls off very slowly till it reaches 1.8 volts per cell in about 7 hours. As the last .1 volt per cell fell in the last 30 minutes the discharge point might be raised to 1.9 volts per cell, and this would make the waste power by resistance only about 5 per cent. for the majority of the discharge or from 2.05 to 1.9 volts per cell. If the lights were needed after the cell had discharged to 1.9 volts, they could be run at the reduced voltage. This resistance method of obtaining

constant voltage is not so wasteful as it appears at first glance. As the battery discharges less power is consumed by resistance, because the resistance is being cut out to maintain constant voltage. Power wasted decreases as the discharge . The voltage regulation could be made automatic by using one of the new automatic rheostats. The rheostat automatically cuts out resistance as the voltage falls off,due to discharge, and cuts in resistance as the battery voltage rises, due to charge. The volt wires of the automatic rheostat should be run from the center of lamp distribution, thus compensating for line drop, and maintaining a constant voltage on the lamps.

On page 34 is a table giving the horse-powers, kilowatts, and amperes at 110 volts developed by windmills varying from 8 1/2 feet to 50 feet in diameter of wheel at 8,16 and 32-mile winds. The power capacities of the battery and complete plant under various conditions are also give, together with the estimated costs of windmill, generator, battery, switchboard, etc. The battery capacity is determined by the maximum power developed at a 32-mile wind, as it is assumed that at this wind velocity the governor operates to prevent a further increase in speed of the mill. At this wind velocity the battery charges at the 3-hour rate, which is nearly its maximum. As a generator can easily stand 25 per cent. overload for three hours, the one chosen has a kilowatt rating 20 per cent. less than the output of the plant during a 32-mile wind. This plan allows the plant to be loaded up to the maximum capacity for any wind velocity.

The cost of the windmill could be considerably reduced by using the old style mill with 4 sweeps. For the large size plants by using a gasoline engine as a reserve a smaller battery,large enough to take care of the fluctuations of the wind, could be used.

Figures 11, 12 and 13 show the wiring scheme of the entire plant, the plan of the generator room and the switchboard connections, respectively.

In estimating the cost of operating a small power plant, the cost of attendance may form a large percentage of the total. The low cost of attendance, the absence of a fuel account, and the low cost of maintenance allows the windmill to still successfully compete with other prime movers for small units.

The uncertainty in the supply is not very serious for pumping where storage can be provided and for many other purposes. Its effect, however, is to increase the size of the mill, and hence the interest and depreciation charges for a given service. This is especially the case for electric lighting where the cost for storage by a storage battery forms an important part of the total, and increases rapidly with the storage capacity. On this account the following estimate of the daily lamp hours available for lighting with a 3/4 Kw. dynamo and a 12 foot aermotor may be of interest.

The power of the mill for different wind velocities is taken from the tests of a similar mill published by E. C. Murphy in the Engineering News, August 19, 1897. He measured the wind velocity with a United States Bureau Anemometer, registering each mile of travel, while the work was measured by means of a friction brake on the driving pulley at the base of the tower. Different weights were used on the brake, giving different speeds for a given wind velocity, and allowing the speed for maximum efficiency to be obtained, as also an approximate value of the loss in power caused by a change in speed. These data are shown in Fig. 4.

Curve (1) gives the belt horse-power of the mill multiplied

by 746, or expressed in watts for different wind velocities in miles per hour when running at the speed for maximum efficiency. Curve (2) gives the corresponding number of revolutions of the belt pulley per minute, while (4) gives the revolutions of the belt pulley approximately for a loss in efficiency of 20 per cent.

The motor is of the solid wheel type. The shaft of the wind wheel is eccentric by several inches with reference to the vertical axis of the turntable; it drives a parallel shaft; intersecting the turntable axis by a spur gear multiplying velocity 3 to 1; the parallel shaft drives a vertical shaft extending down the hollow axis of the turntable by a bevel gear multiplying velocity 2 to 1. The vertical shaft drives the belt pulley at the bottom of the tower by a bevel gear without changing the velocity. The wheel is held into the wind by a spring extending back to the tail bone of the vane and by the torque of the vertical shaft; it governs out by the eccentricity of the wind pressure upon the wheel with reference to the turntable. The tension of the tail spring has a slight adjustment so that curve (1) can be modified somewhat for the higher winds.

The dynamo was tested by charging a 60-cell storage battery having a voltage of 114 at the beginning of the test. The voltage and the charging and shunt field currents were directly measured. The total belt horse-power was estimated, or rather the frictional and other losses, no means for measurement having been at hand.

The results of this test are shown in Fig. 5. The watts are given on the right, and the voltage on the left, both in terms of the speed of rotation of the dynamo.

The dynamo is differential wound, the main current reducing the strength of the field produced by the shunt current, which

accounts for the slow rise in voltage and horse-power with velocity.

By equating belt horse-power of dynamo and motor, the dynamo revolutions can be plotted in Fig. 4, as also the corresponding charging current, giving both in terms of wind velocity. A test of the 20 candle-power tungsten lamps to be used showed them to take 0.227 amperes of current at 110 volts. Accordingly, it is assumed that .245 amperes of charging current at 114 volts would be required per lamp supplied by the storage battery, allowing for battery amd line wire efficiency. Accordingly, the charging current for Fig. 4 (3) is given in lamps (at the left edge of the plate).

By dividing the dynamo revolutions by the motor belt wheel revolutions for maximum efficiency, it is seen that the quotient is not constant; thus:

$$\frac{600}{133}=4.5;\ \frac{700}{170}=4.1;\ \frac{800}{216}=3.7;\ \frac{900}{253}=3.5;\ \frac{1000}{286}=3.5\ ;\ \frac{1100}{310}=3.5\ ;\ \frac{1200}{333}=3.6$$

Efficiency for light winds being of most importance, a ratio of 4.4 was assumed. By dividing the dynamo revolutions, 600, 700, etc., by 4.4, the corresponding revolutions of the motor pulley are obtained, curve (5). A comparison of (5) with (2) shows a considerable slowing down of the motor for high winds. This by (4) gives an estimated loss of 4 per cent. in the power of the motor at 700 revolutions of the dynamo, 20 per cent. at 800, and 30 percent. at 900 revolutions, giving (6) as the best approximation to the actual available 20 candle-power tungsten lamps in terms of wind velocity, which can be obtained from the data. In other words, (6)gives the number of 20 candle-power tungsten lamps which can be supplied through the storage battery for different wind velocities according to the assumptions made.

The next step is to find the wind velocity available day

by day, in order to find the capacity of the plant. The velocity is taken from the sheets of the self-recording Richard Freres anemometer of the New York State branch of the United States Weather Bureau at Ithaca. The anemometer is on the top of the Mc Graw tower, some 140 feet from the ground, with the surrounding country for several miles generally lower, except to the east, where it gradually rises. The recording velocity curve is continuous, the coordinates being time and distance.

For each day the number of hours for each wind velocity is multiplied by the number of lamps for that velocity taken from curve (6) Fig. 4, and the products added for the lamp hours for that day. In Fig. 6, these sums are plotted for the year beginning July 1,1897. Lines are drawn on each plate showing the inclinations for 20, 30, 40, 50 and 60 lamp hours per day, so that the general inclination of the curves in lamp hours can be estimated for any period. If, for example, the dotted line in July marked "40 h.p.d." be compared with the small diagram it will be found to be parallel to the line marked 40; the 35 line in October will be found to be midway between the 30 and the 40 line of the small diagram. Lines are also drawn showing minimum supplies in periods of calm for an assumed storage battery capacity of 240 lamp hours. The lowest for the year is 22 lamp hours per day from May 19th to June 17th, or nearly a month when the evenings are short. The 35 lamp hours for two weeks in October, the 38 lamp hours for nearly a month from November 19th, and the 36 lamp hours for about two weeks in February, fix the real limits of the plant for the year as they occur when the full lighting capacity is required.

A similar computation has been made for a 16-foot aeromotor

running the same dynamo on the assumption that the power increases as the square of the diameter up to the capacity of the dynamo. With these curves and the same storage capacity of 240 lamp hours, the May minimum was brought up to 38 lamp hours per day, and the time shortened to the two weeks from May 22nd to June 7th. The October minimum was raised to 58 lamp hours for 10 days, the November minimum was raised to 70 lamp hours for 22 days, and the February to 64 lamp hours for the same two weeks.

The 12-foot aermotor has thus a minimum capacity under the conditions assumed of 38 lamp hours (20 candle-power tungsten lamps) per day during the season of maximum lighting, and the 16-foot a minimum capacity of 70.

Increased storage capacity would appreciably increase the capacity with the 16-foot aermotor, while it would have but slight effect with the 12-foot.

Diam. of Wheel in Ft.	R.P.M. at 16 M.P.H.	H.P. at Wd. Vel. (Miles per Hour) 8	16	32	K.W. at Wd. Vel. (Miles per Hour) 8	16	32	Amps. at Wd. Vel. (at 110 volts) (Miles per Hour) 8	16	32	Amp. Cap. Battery 8 hour rate	Amp. Hour Cap. Battery	Lamp Hour Cap. Battery based on 1.25 W. per CP with 25 W. Tungsten Lamp	Lamp Hour Cap. of Plant for 8 mile breeze for 12 hours.	Cost of 60 Cell Battery Based on 3 hr. charge rate	Cost of Generator Running 25% over for 3 hrs at 32 mile wind	Cost of Wind Mill (Steel) (Disk)	Cost of Switchboard, Slate 3 C.B., 2 Meters, Switches Etc.	Cost of Automatic Voltage Regulator and Automatic Armature Switch	Cost of Plant.
8.5	75	.012	.05	.2	.009	.037	.148	.082	.336	1.35	.75	6	26.3	4.3	$50	$38	$450	$80	$40	$658
10	65	.04	.15	.6	.0298	.112	.447	.25	1.02	4.06	2	16	70.5	13.2	150	45	500	80	40	815
12	60	.06	.26	1.04	.045	.194	.775	.41	1.76	7.04	4½	36	158	21.5	210	55	560	80	40	945
14	55	.09	.35	1.4	.104	.26	1.05	.60	2.38	9.55	5	40	176	31.7	300	65	620	80	40	1105
16	50	.169	.50	2.0	.126	.37	1.49	.84	3.36	13.6	7.5	60	264	44.5	400	80	680	80	40	1280
18	45	.19	.75	3.0	.142	.56	2.24	1.29	5.1	20.4	10	80	350	68.0	510	100	750	85	45	1490
20	40	.25	1.00	4.0	.187	.746	2.98	1.7	6.78	27.1	15	120	530	90	630	130	825	85	45	1715
25	35	.44	1.75	7.0	.328	1.31	5.22	2.96	11.9	47.4	25	200	880	157	1000	170	1000	85	45	2300
30	28	.83	3.33	13.3	.62	2.49	9.93	5.64	22.6	90.0	50	400	1760	300	2000	250	1300	90	50	3690
40	22	1.0	7.5	30.0	.746	5.6	22.4	12.6	51.0	204	100	800	3500	667	4000	430	1500	100	55	6085
50	18	3.0	12.0	48.0	2.24	8.95	35.8	20.4	81.3	326	160	1280	5620	1070	7000	680	1800	115	60	9655

Capacities and Costs of Windmill Electric Plants.

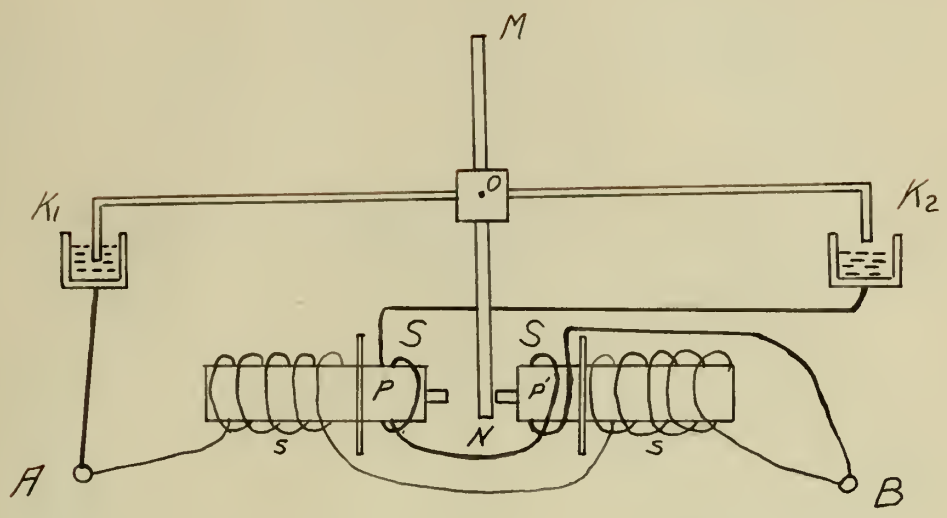


Fig. 1.

Devices of Askow Plant.

(1) Automatic Armature Switch.

(2) Speed Regulating Scheme.

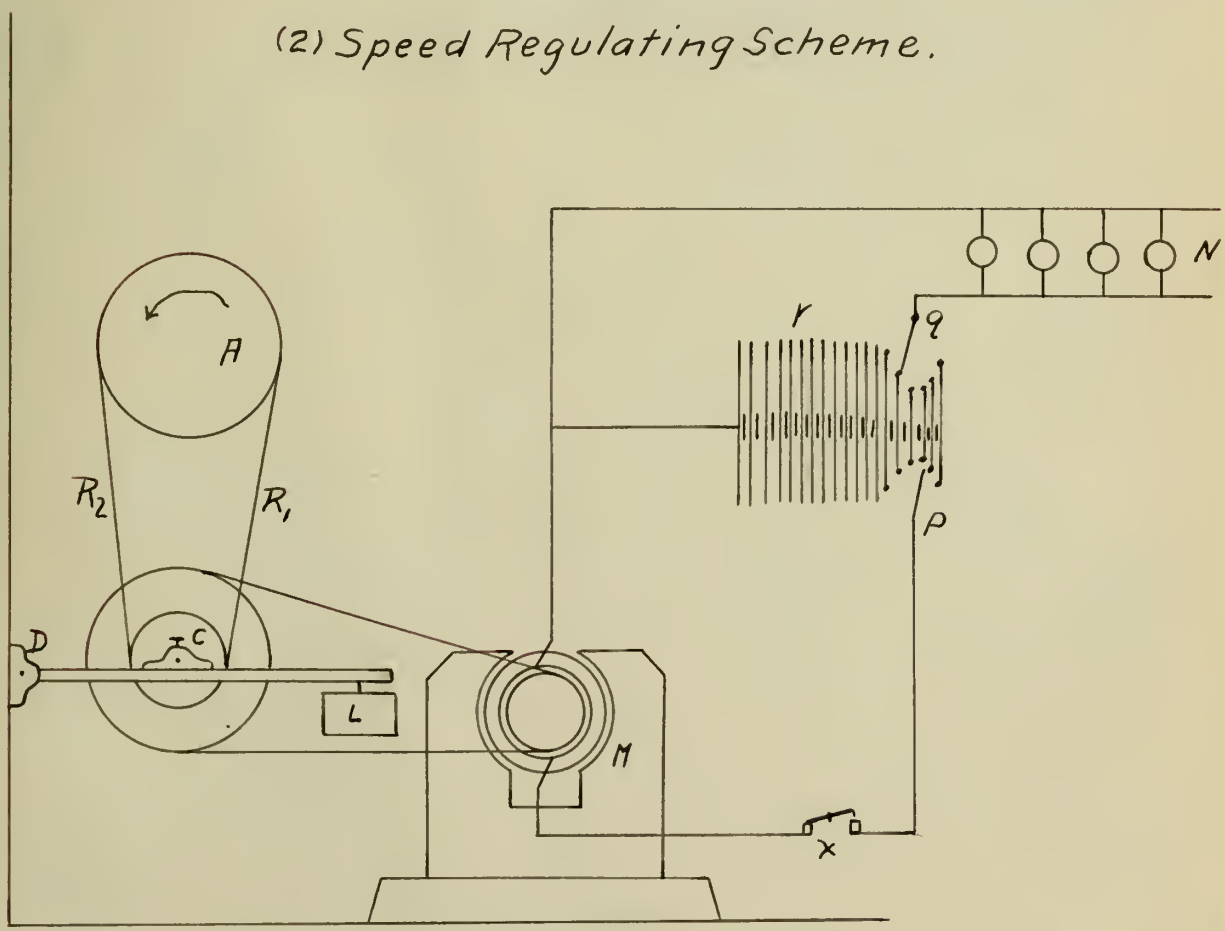
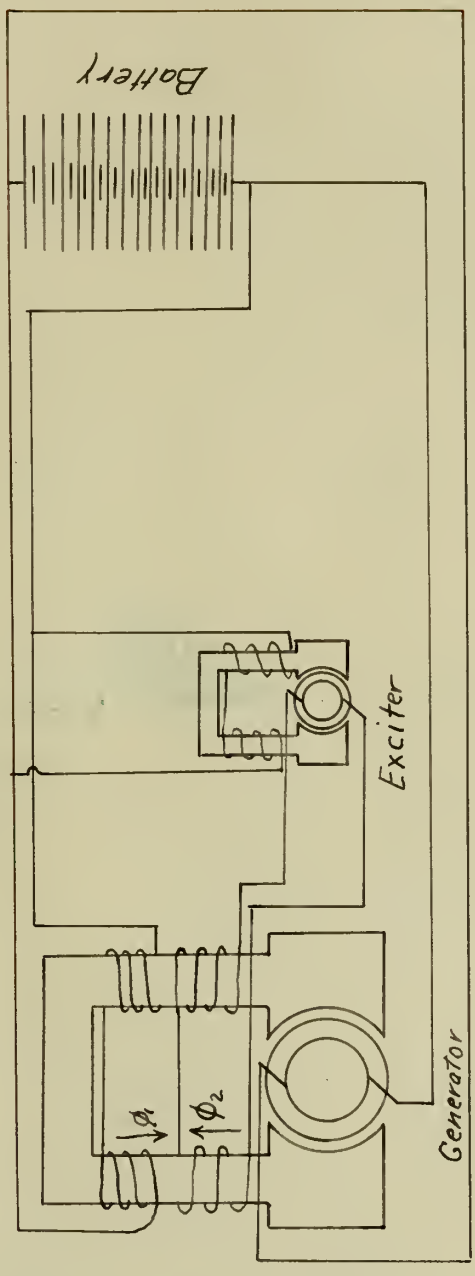


Fig. 2.



Car Lighting Generator Set
Fig. 3.

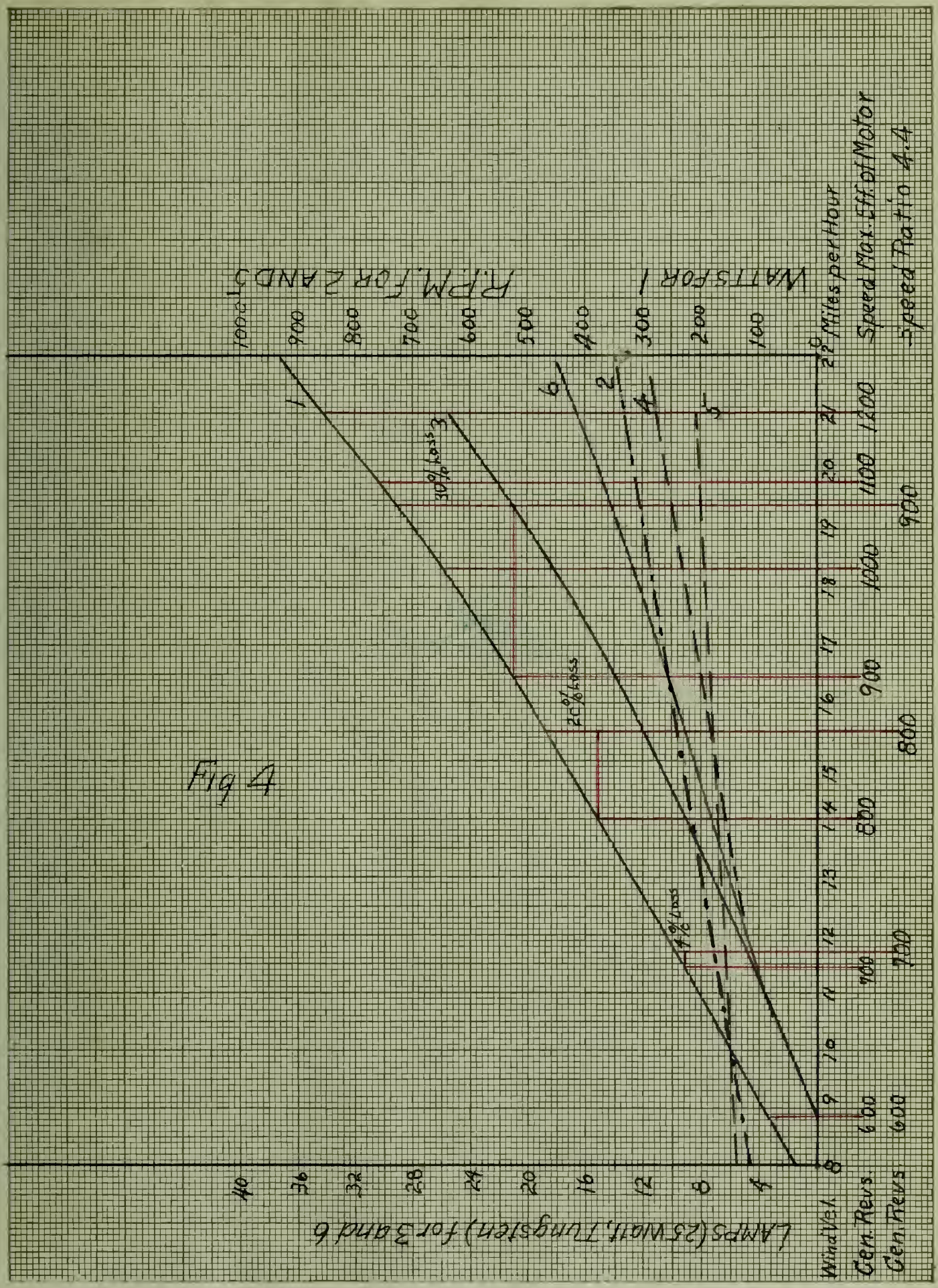


Fig 4

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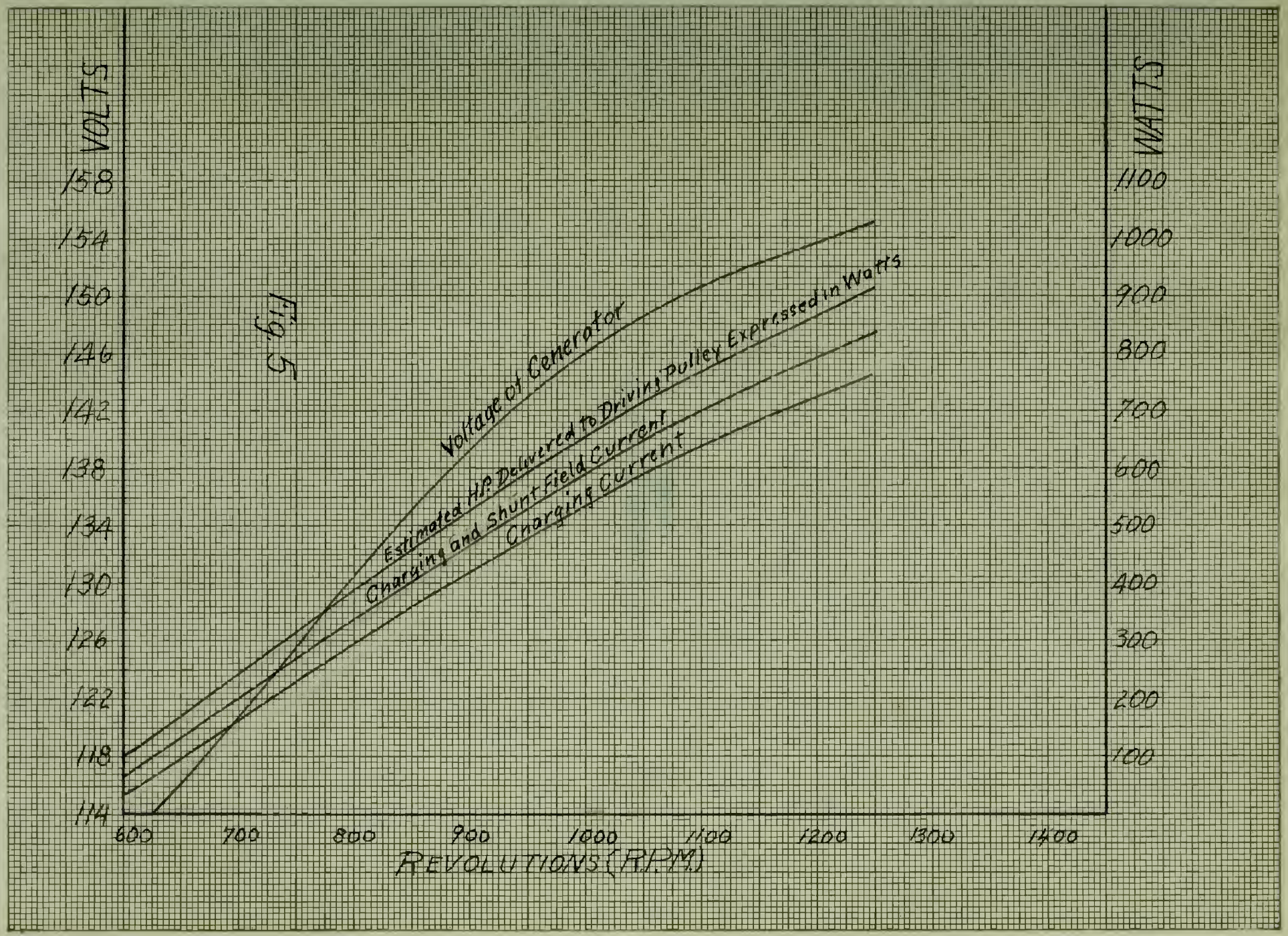

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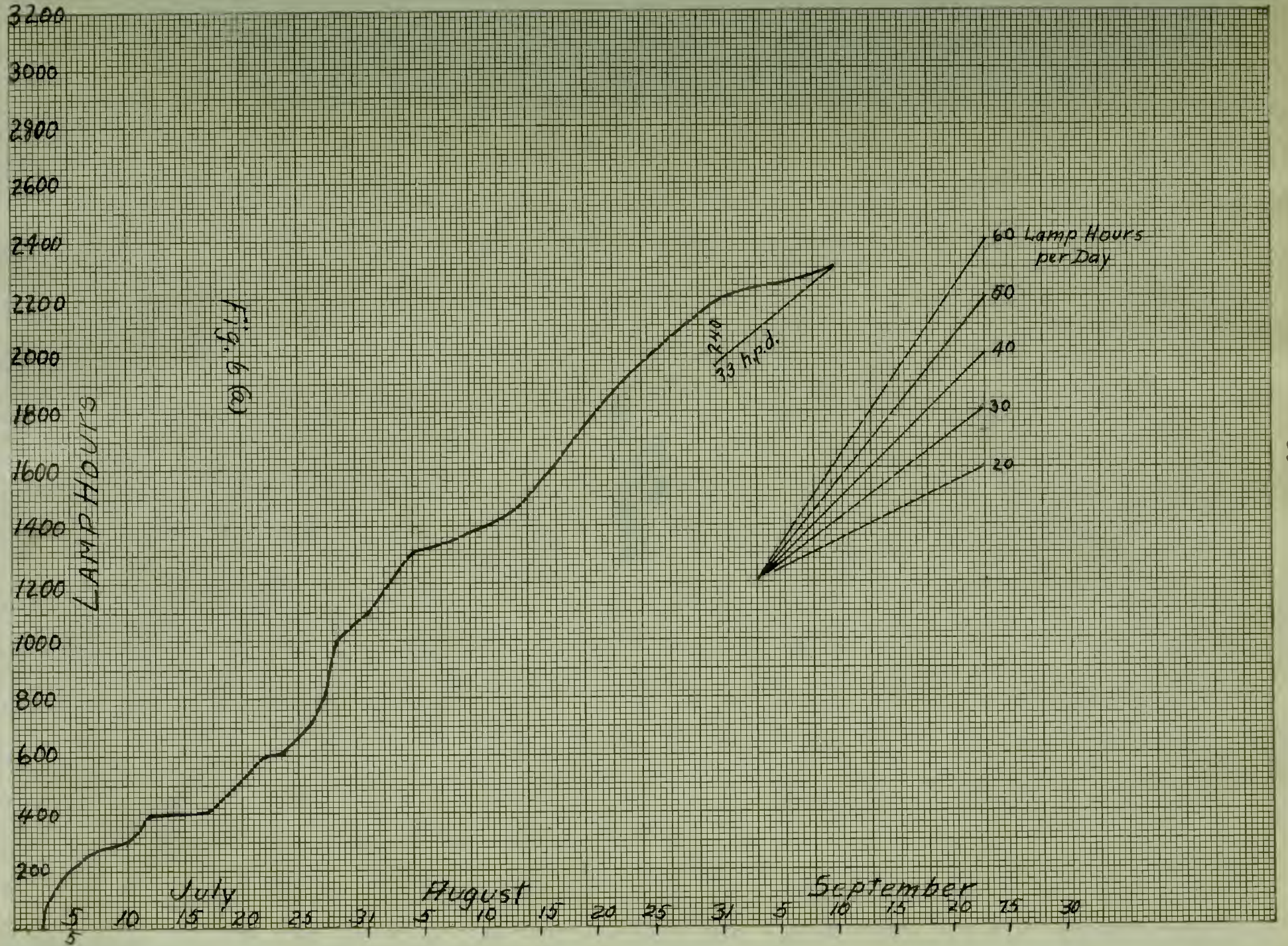

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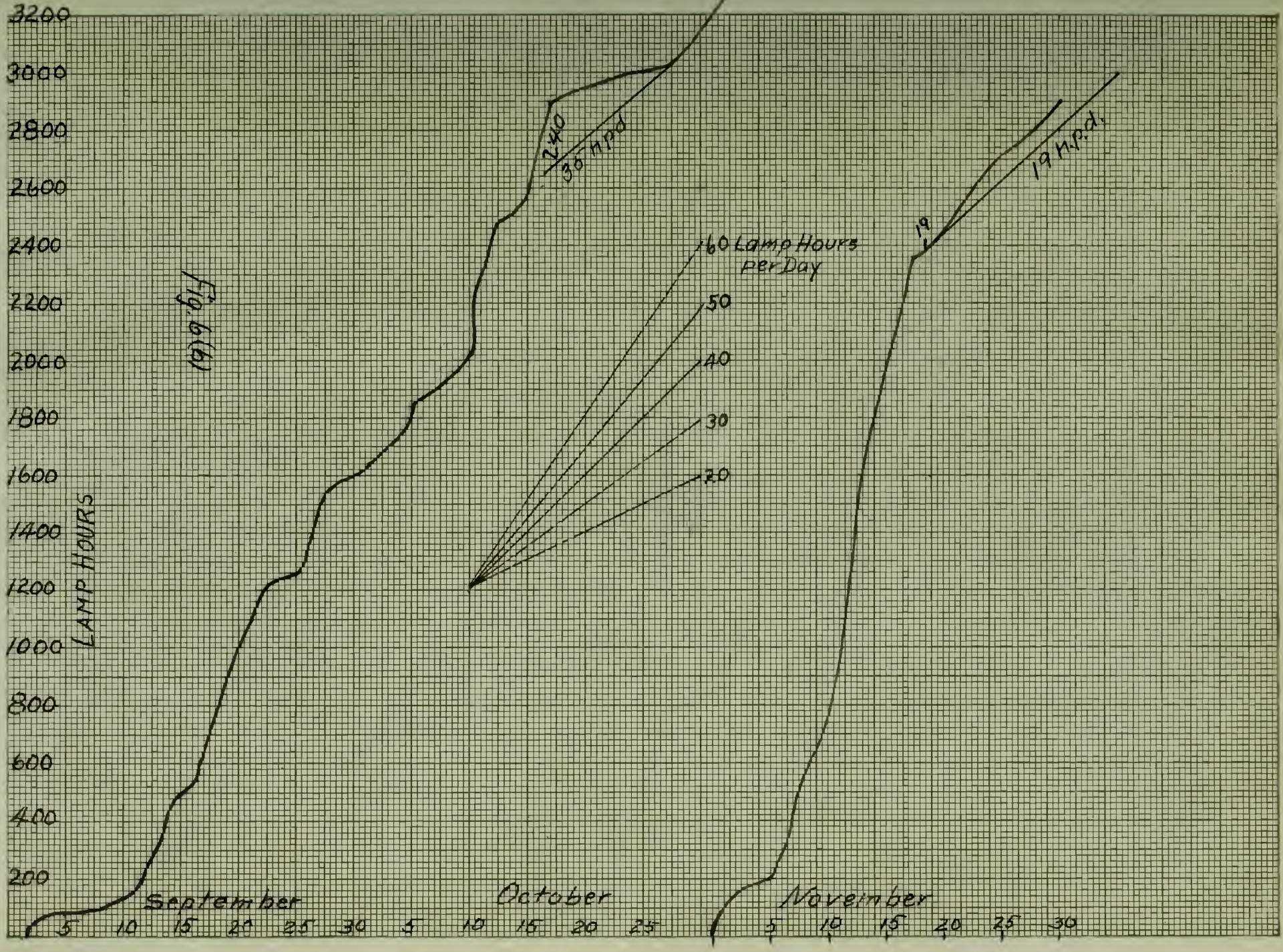

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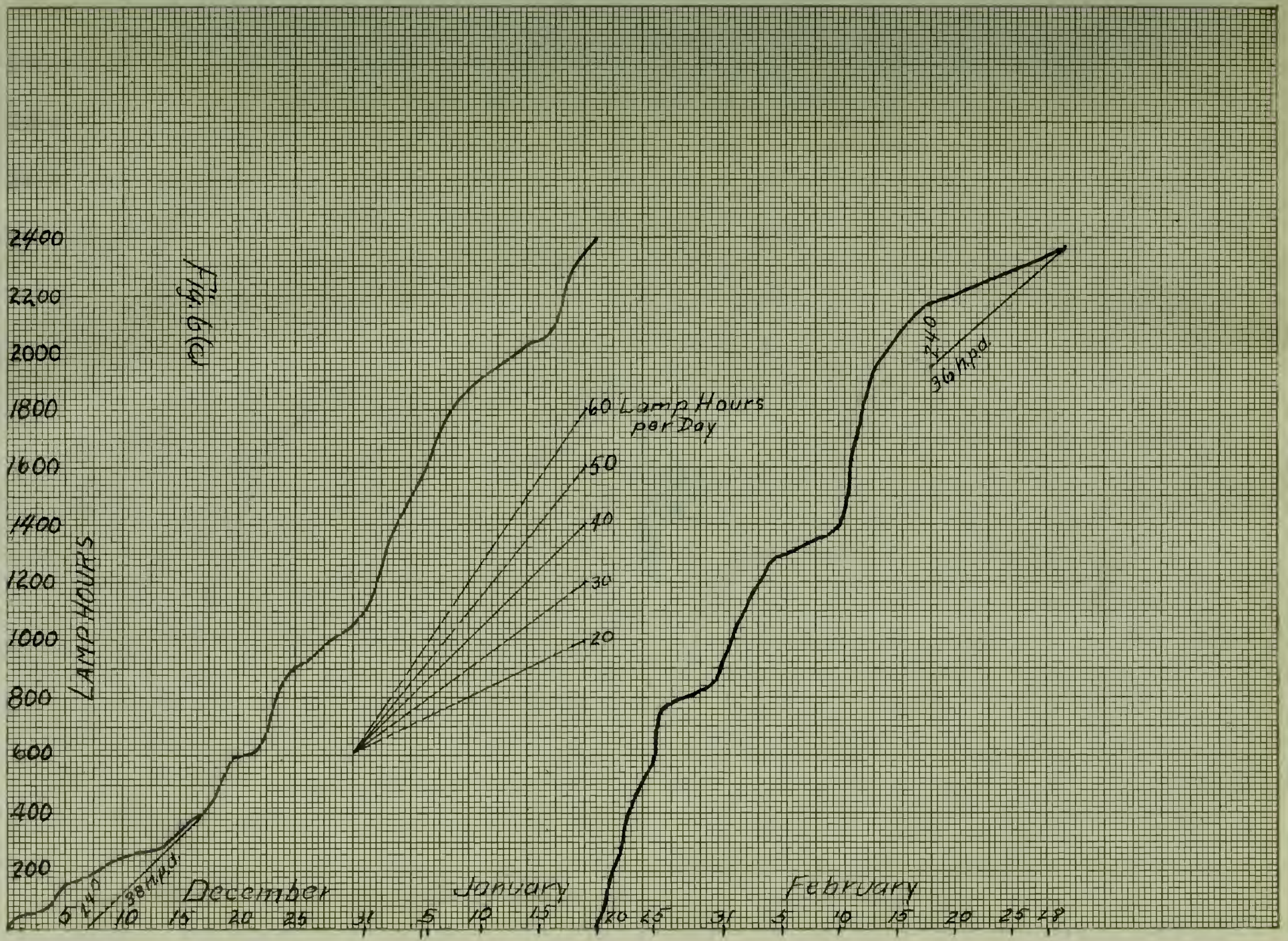

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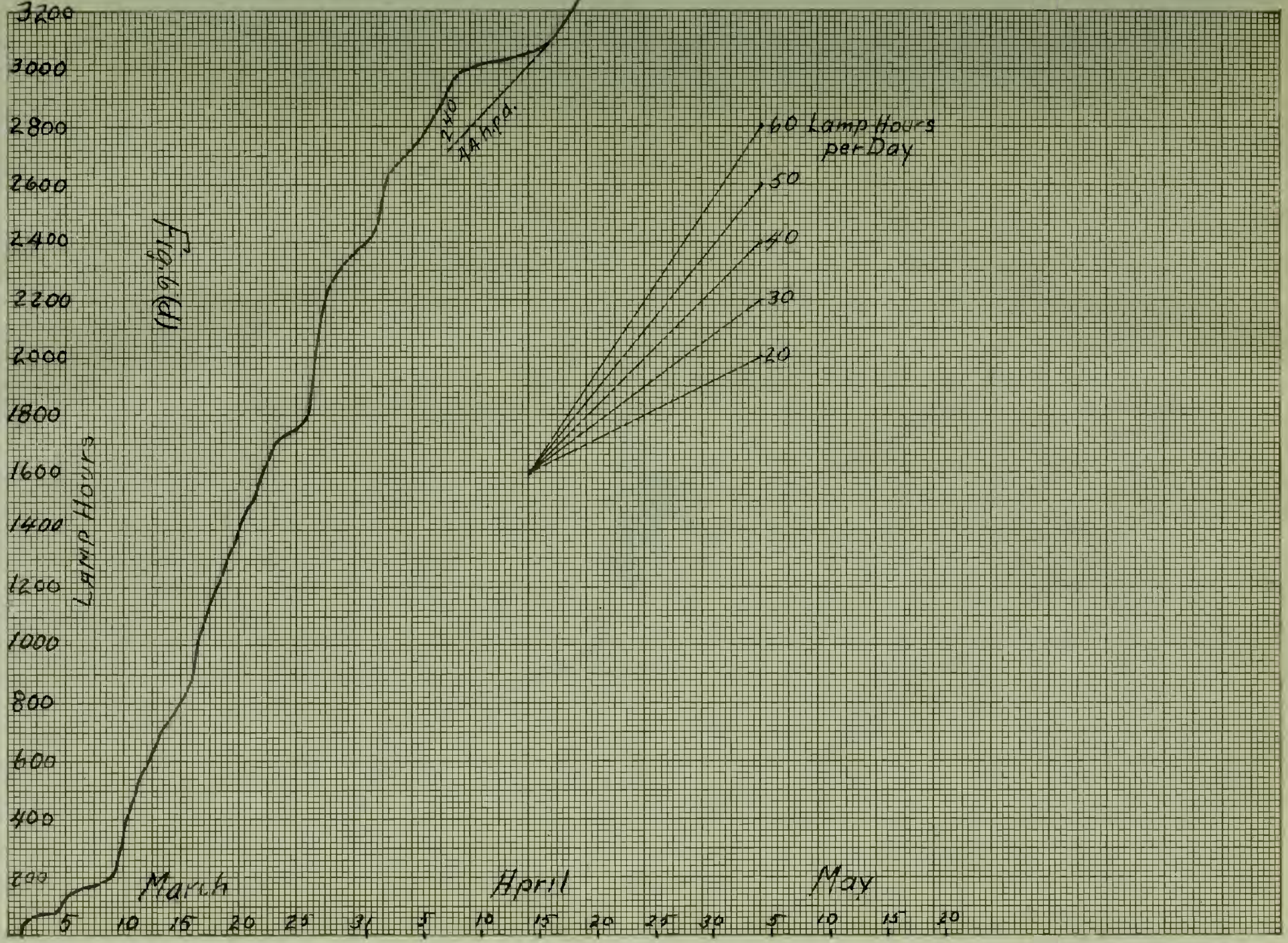

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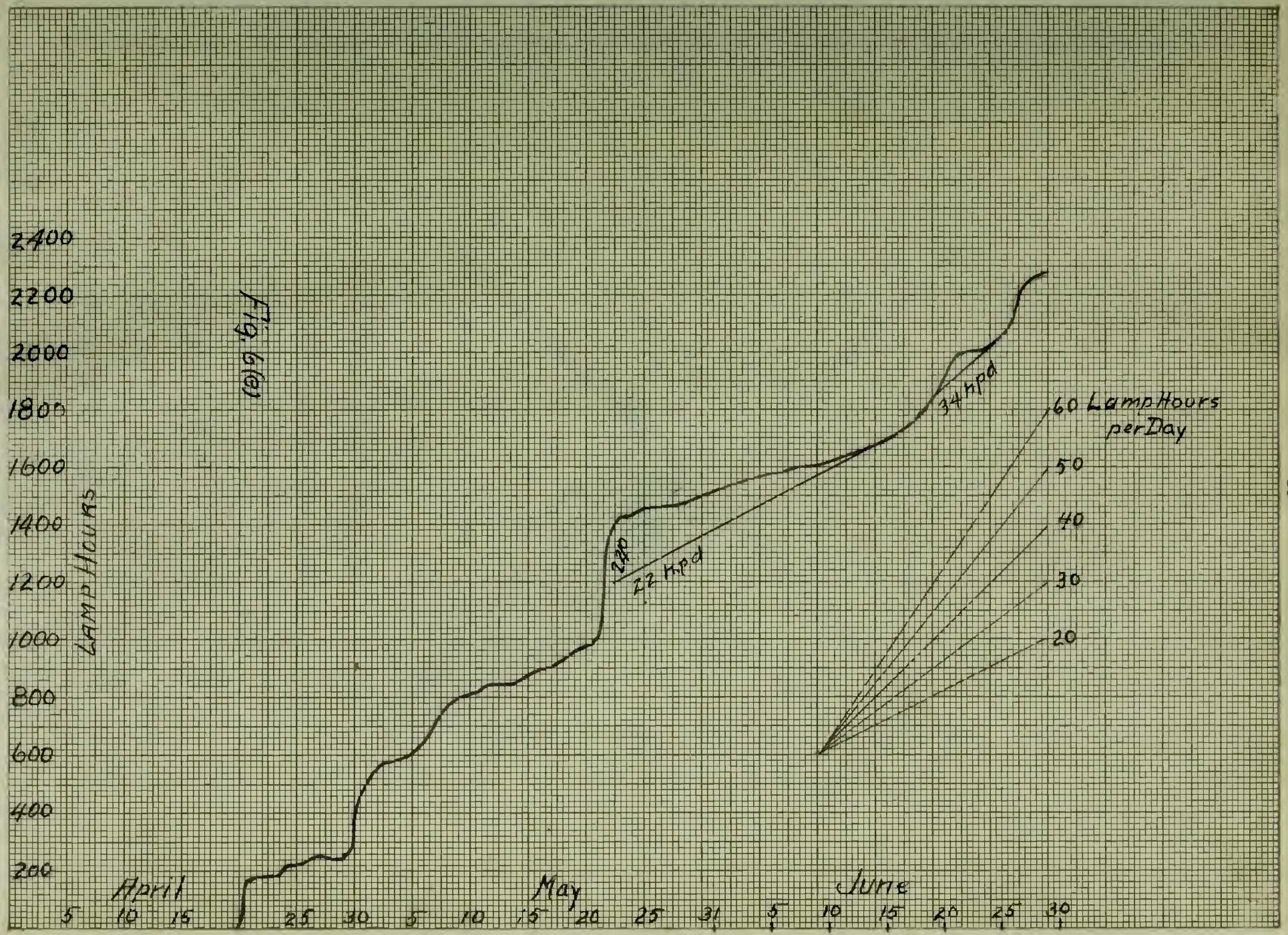


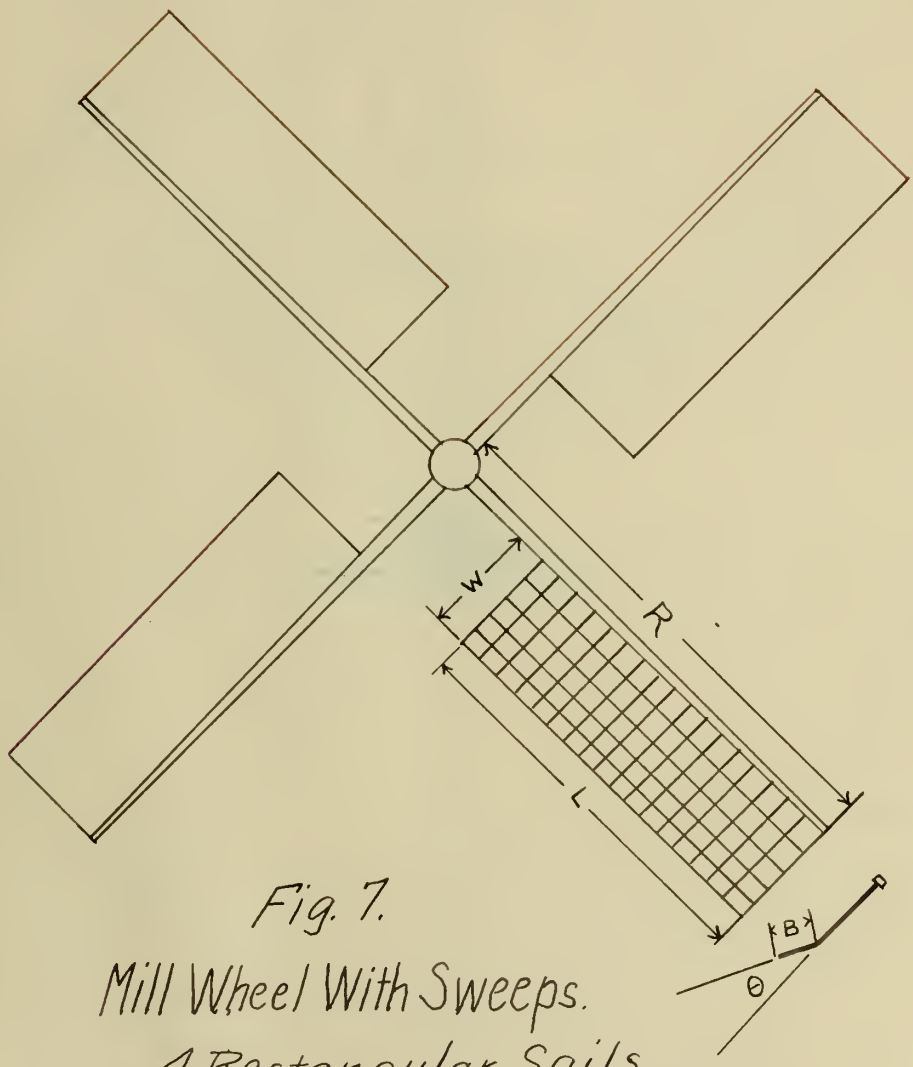


Fig. 7.

Mill Wheel With Sweeps.

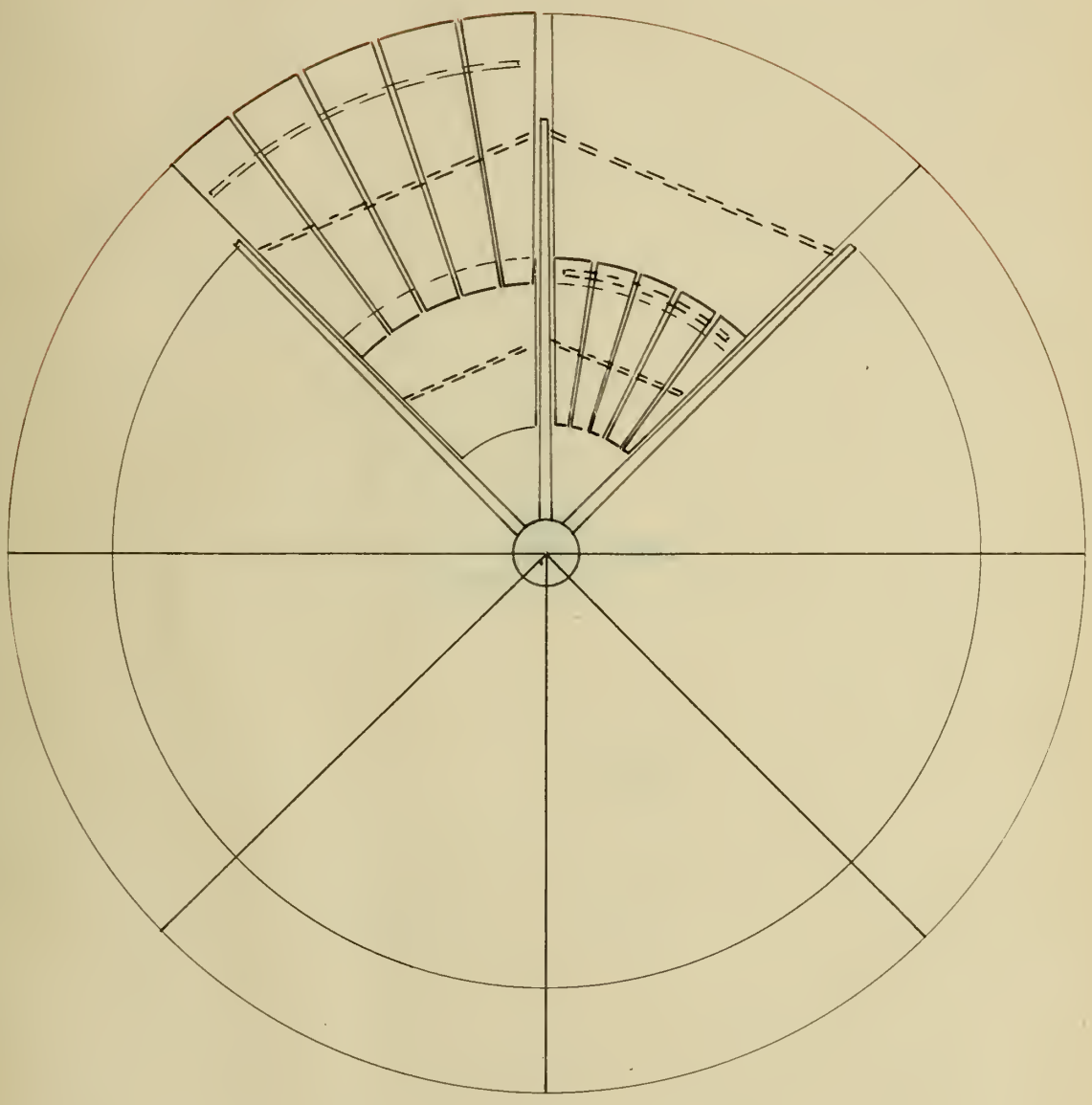
4 Rectangular Sails.

$L = \frac{3}{4} R$

$W = \frac{1}{4} R$ to $\frac{1}{5} R$

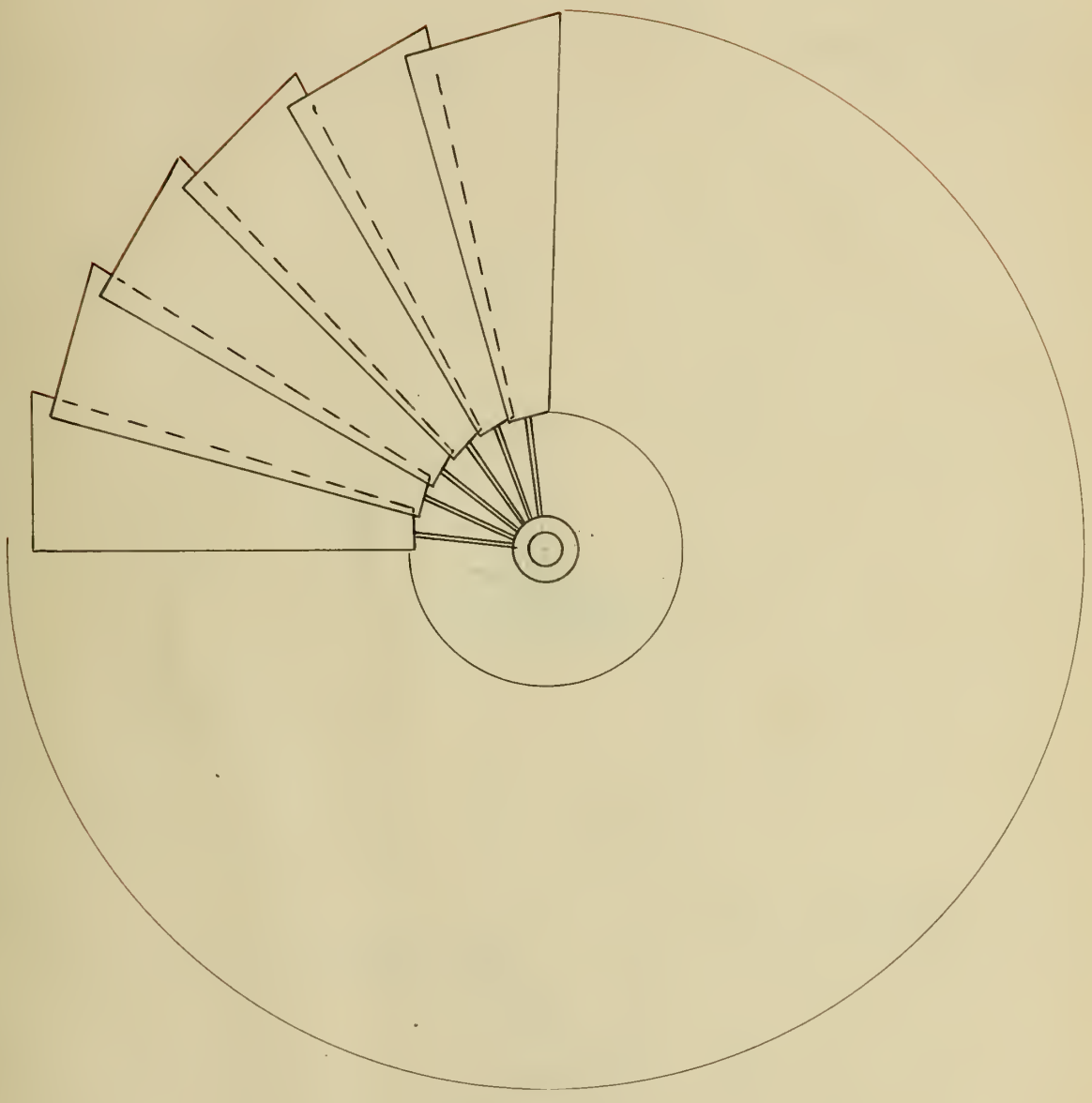
$\theta = 10°$

$B = \frac{1}{4} W$ to $\frac{1}{6} W$



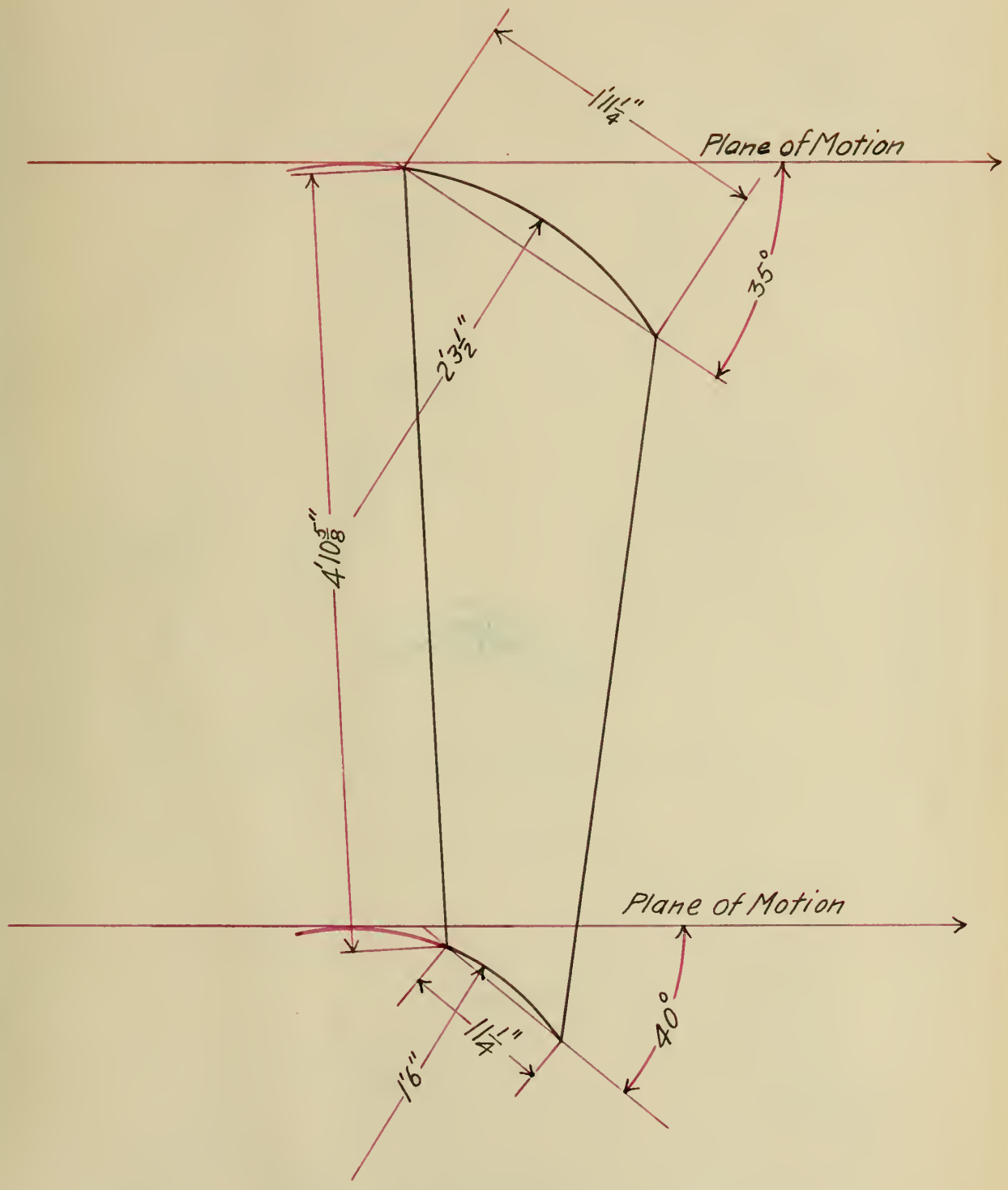
Mill Wheel with Movable Shutters.

Fig. 8.



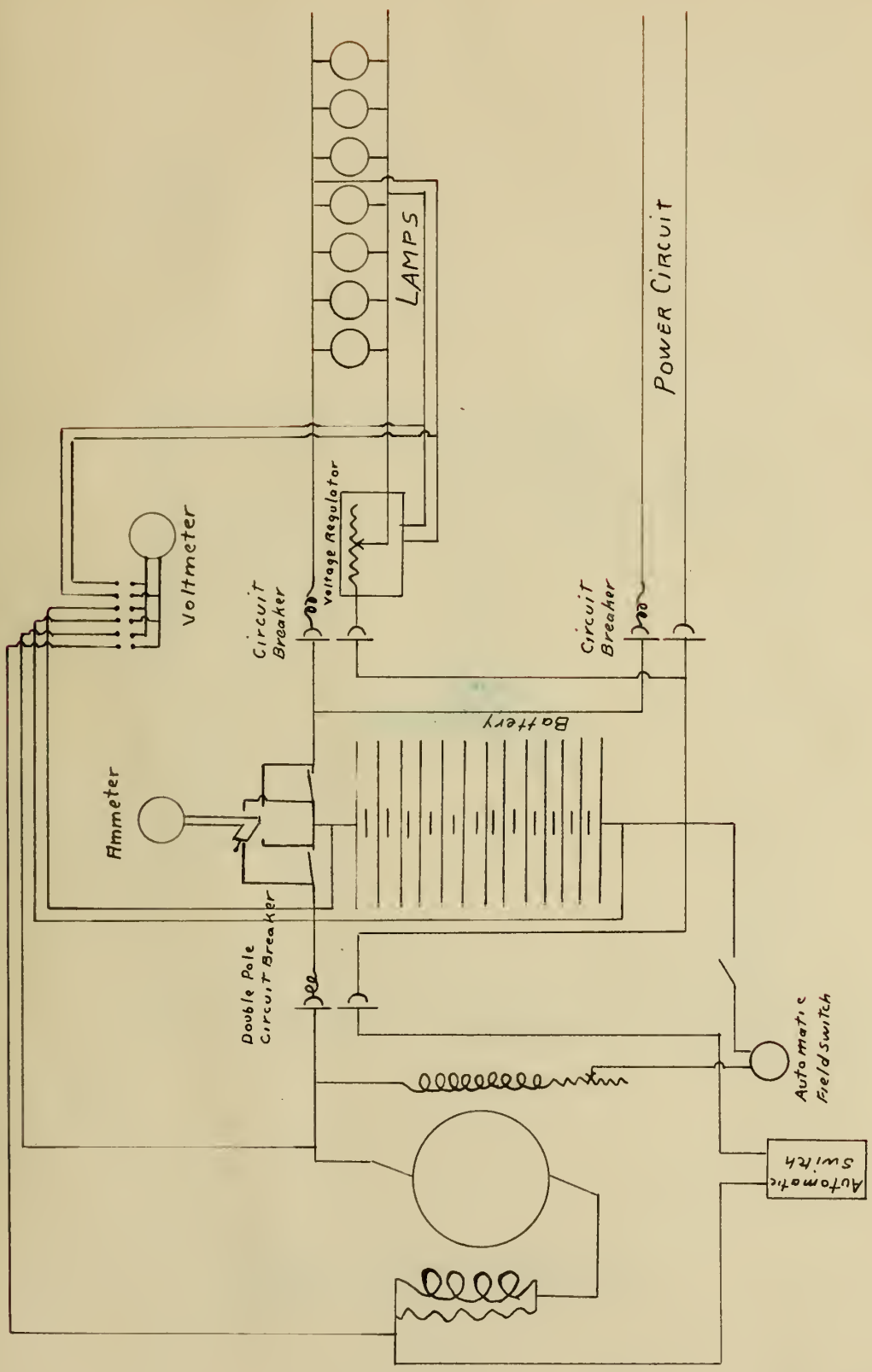
Disk Windmill Wheel

Fig. 9.



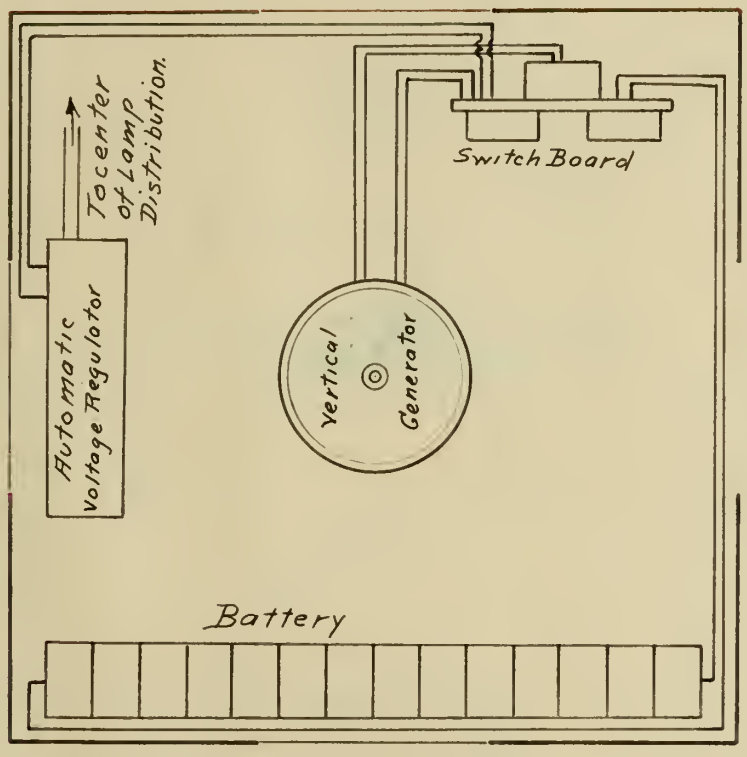
Blade of Disk Mill.

Fig. 10.



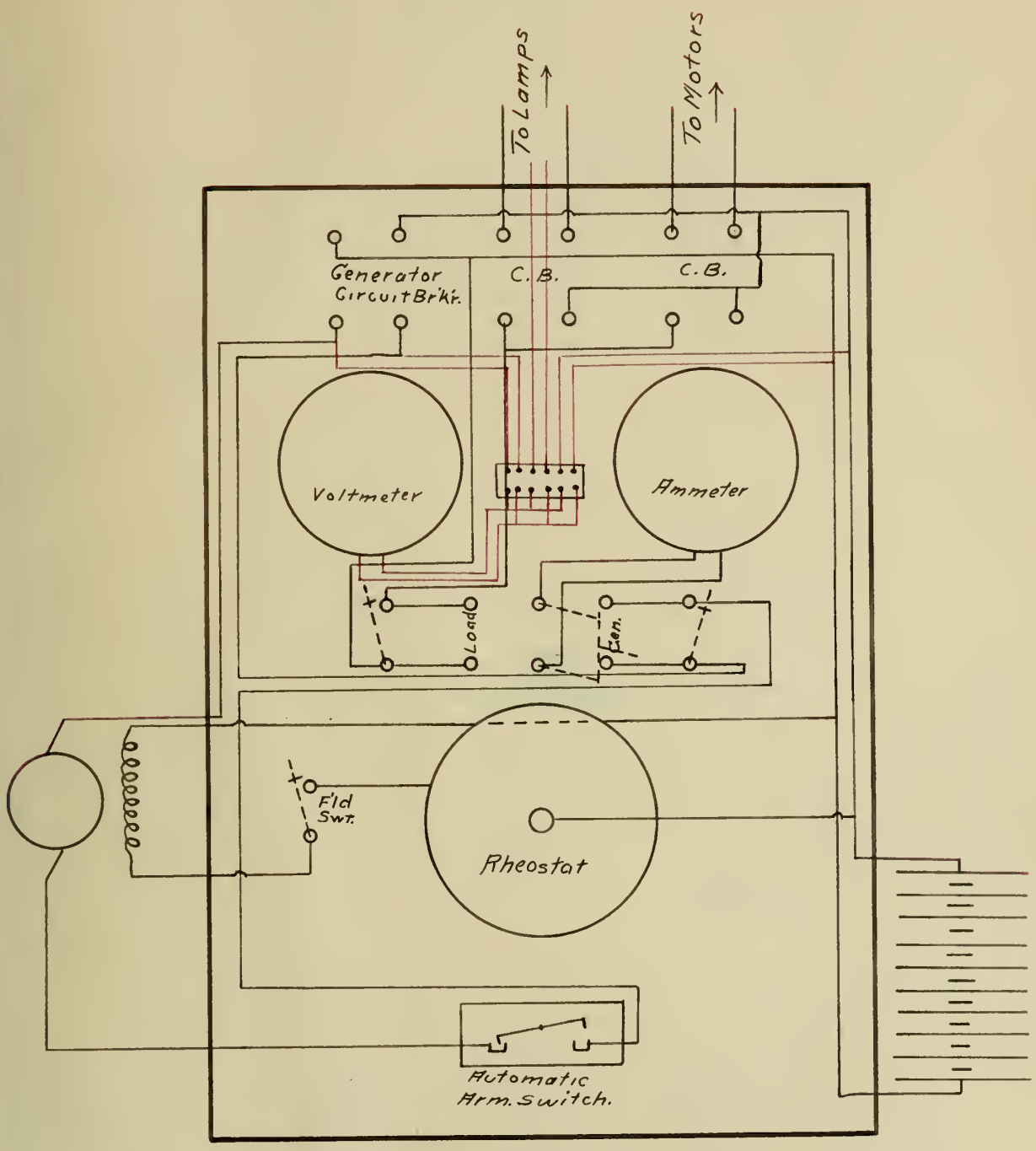
Wiring Diagram of Windmill Electric Plant.

Fig. 11.



Plan of Generator Room

Fig. 12



Switch Board

Rear View.

Fig. 13.

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